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PRACTICAL HYDRAULICS:

A SERIES

OF

RULES AND TABLES

FOR

THE USE OF ENGINEERS, &c. &c.

BY

THOMAS BOX.

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PREFACE.

The Reader must not expect in this little book, an exhaustive treatise on Hydraulics; many such have been written, and they leave little or nothing to be desired. This work consists of a series of Rules and Tables, giving unusual facility for the solution of questions which occur in the daily practice of Engineers.

For the two leading questions: the discharge of pipes, and of open channels, two sets of Tables are given, the reason for which may not be obvious; but it is impossible to give Tables combining extreme facility and extreme accuracy for low heads, and the author has therefore given two Tables, one giving accurate results in all ordinary cases, with the least possible labour, and the other, giving with more labour, exact results in extreme cases.

For the most part, the Rules and Tables have been long used in an extensive practice, and the principal reason for publishing them, is the author's desire that the profession from which he has retired, may have the benefit of Tables, &c., which for many years, have been very useful to himself.

EASEDALE,
GRASMERE.
July, 1867.

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ERRATA.

Page 10, line 11, *for* 2100, *read* 2000.
„ „ „ 13, *for* 200, *read* 100.
„ 13, „ 17, *for* $\frac{3.244}{300}=.010814$, *read* $\frac{3.224}{300}=.01075$.
„ „ „ 34, *for* .0595, *read* .00595.
„ 33, „ 7, *for* 83, *read* 84.

HYDRAULICS.

(1) The velocity with which water issues from the side of a vessel, as at A, Fig. 35, is the same as that of a body falling freely by gravity from the height H, or the distance from the centre of the orifice to the surface of the water. This velocity is given by the rule $8 \times \sqrt{H} = V$, in which H is the head in feet, and V the velocity in feet per second.

(2) But it has been found, by experiment, that the converging currents of water approaching the orifice (especially where that is made in a thin plate) cause a contraction in the issuing jet of water; so that, instead of a parallel jet, it becomes a conical one, as shown by Fig. 4, which represents an orifice of 1 inch diameter in a thin plate. The diameter of the most contracted part of the jet is ·784 of the diameter of the orifice, and its proportional area will therefore be $\cdot784^2 = \cdot615$, and it occurs at a distance of half an inch from the plate as shown. The part from B to C may be taken as a curve, with a radius of 1·22 times the diameter of the orifice in the plate. The formula $8 \times \sqrt{H} = V$ gives the velocity of discharge at the point of greatest contraction, and the quantity of water discharged must be calculated for the reduced area at that point; but we may calculate the discharge more directly by the following rule: $\sqrt{H} \times d^2 \times 16{\cdot}3 = G$, in which

H = the head on the centre of orifice in feet.
d = diameter of the orifice in inches.
G = gallons discharged per minute.

Thus, for the discharge of an orifice 3 inches diameter, in a thin plate, and with a head of 16 feet, we have, $\sqrt{16} \times 3^2 \times 16{\cdot}3$, or $4 \times 9 \times 16{\cdot}3 = 586$ gallons, with no contraction of vein; but with a thin plate as in Fig. 4, this is reduced to

Table No. I.—Of the Theoretical Discharge of Water by Round Apertures of various Diameters, and under Different Heads of Water Pressure.

Diameter in Inches.	Head of Water in Inches.																
	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	22	24
	Discharge in Gallons per Minute.																
1	4·7	6·6	8·1	9·4	10·5	11·5	12·4	13·3	14·1	14·8	16·2	17·6	18·8	19·9	21	22	23
2	18·8	26·4	32·4	37·6	42·0	46·0	49·6	53·2	56·4	59·2	64·8	70·4	75·2	79·6	84	88	92
3	42·2	59·4	72·9	84·6	94·5	103	112	120	127	133	146	158	169	179	189	198	207
4	75·2	106	130	150	168	184	198	213	225	237	259	281	301	318	336	352	368
5	117	165	203	235	262	287	310	332	352	370	405	440	470	497	525	550	575
6	169	237	291	338	378	414	446	479	507	533	583	663	677	716	756	792	828
7	230	310	397	460	514	563	607	652	691	725	794	862	921	975	1029	1078	1127
8	301	422	518	601	672	736	793	851	902	947	1037	1126	1203	1273	1344	1408	1472
9	381	534	656	761	850	931	1006	1077	1142	1199	1312	1425	1523	1612	1701	1782	1863
10	470	660	810	940	1050	1150	1240	1330	1411	1480	1620	1760	1880	1990	2100	2200	2300
12	676	952	1168	1353	1512	1656	1785	1915	2030	2134	2333	2534	2707	2865	3024	3170	3312
14	920	1241	1588	1842	2058	2254	2430	2606	2764	2901	3175	3450	3684	3900	4116	4312	4508
16	1203	1690	2074	2406	2688	2944	3174	3405	3610	3789	4147	4506	4813	5094	5376	5632	5888
18	1523	2138	2624	3045	3402	3726	4018	4309	4568	4795	5249	5702	6091	6447	6804	7128	7452
20	1880	2640	3240	3760	4200	4600	4960	5320	5640	5920	6480	7040	7520	7960	8400	8800	9200
22	2275	3194	3920	4550	5082	5566	6002	6437	6824	7163	7841	8518	9099	9632	10164	10648	11132
24	2704	3808	4672	5414	6048	6624	7140	7660	8120	8536	9332	10136	10829	11460	12096	12680	13248
30	4230	5940	7290	8460	9450	10350	11160	11970	12690	13320	14580	15840	16920	17910	18900	19800	20700
Velocity in feet per second ...	2·32	3·275	4 01	4·63	5·18	5·67	6·13	6·55	6·95	7·32	8·03	8 67	9·27	9.83	10·36	10·87	11·35

586 × ·615 = 360 gallons per minute. The following Table No. I. gives the theoretical discharge, calculated by the foregoing rule. It may be easily applied to cases beyond its own limit, for the discharge is proportional to the square root of the head and to the square of the diameter; so that discharges in the ratio 1, 2, 3, 4, &c., will be given by heads in the ratio 1^2, 2^2, 3^2, &c., or 1, 4, 9, 16, &c. Thus the discharge of a 3-inch orifice with 16 feet head, which we found to be 360 gallons, may be found by table; for the discharge with 16 feet head will be $\sqrt{16} = 4$ times the discharge with 1 foot head, which latter by table is 146 gallons; therefore the discharge would be 146 × 4 × ·615 = 360 gallons as before.

(3) When the aperture is of considerable thickness, or has the form of a short tube, not less in length than twice the diameter of the orifice, the contraction is less, and the discharge greater, than by a thin plate. This case is shown by Fig. 5. Here, for a tube 1 inch diameter, the most contracted part is ·9 inch diameter, and its proportional area is $\cdot 9^2 = \cdot 81$ This is a case that often occurs in practice; such, for instance, as where an outlet pipe is taken through the side of a reservoir, as in Fig 36. Table II. gives the head necessary for *short* tubes, like Fig. 5, discharging different quantities of water. Thus a 7-inch pipe, with 450 gallons, would require 6 inch head to generate the velocity, and this is irrespective of friction, which, in fact, for so short a tube, would be practically nothing.

(4) *Friction of Long Pipes.*—When a pipe discharging water is of considerable length, there is a loss of head, due simply to the friction of the water against the side of the pipe, so that in all cases the head consumed may be considered as composed of two portions: one, the amount due to the velocity of entry irrespective of friction; and the other, the amount due to friction alone irrespective of the amount due to velocity. Thus, in Fig. 6, the head h gives a certain velocity of discharge by the short pipe A; but to give the same velocity in the long main B C, the head H^1 is necessary, of which h^1 is consumed in generating the velocity of entry, same as in A, and H, in the friction of the long pipe, and the total head is of course the sum of the two.

(5) The loss of head by friction may be calculated by the following rules, in which

TABLE II.—Of the Actual Discharge of Short Tubes of various Diameters, with Square Edges and under Different Heads of Water Pressure, being $\frac{8}{10}$ths of the Theoretical Discharge.

Diam. in Inches.	HEAD OF WATER IN INCHES.																
	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	22	24
	DISCHARGE IN GALLONS PER MINUTE.																
1	3·76	5·28	6·48	7·52	8·4	9·2	9·9	10·6	11·3	11·8	12·96	14·1	15·0	15·9	16·8	17·6	18·4
2	15·04	21·12	25·9	30·1	33·6	36·8	39·7	42·6	45·1	47·4	51·8	56·3	60·2	63·7	67·2	70·4	73·6
3	33·8	47·5	58·3	67·7	75·6	82·4	89·6	96·0	101·6	106·4	116·8	126	135	143	151	158	166
4	60·2	84·8	104	120	130	147	158	170	180	189	207	225	241	254	269	282	294
5	93·6	132	162	188	210	230	248	266	282	296	324	352	376	398	420	440	460
6	135	190	233	270	302	331	357	382	406	426	466	530	542	573	605	634	662
7	194	248	318	368	411	450	486	522	553	580	636	689	737	780	823	862	902
8	241	338	414	481	538	589	634	681	722	758	829	901	962	1018	1075	1126	1178
9	305	427	525	609	680	745	805	863	914	959	1049	1140	1218	1290	1361	1426	1490
10	376	528	648	752	840	920	992	1064	1129	1184	1296	1408	1504	1592	1680	1760	1840
12	541	762	934	1082	1210	1325	1428	1532	1624	1707	1866	2027	2166	2292	2419	2536	2650
14	736	993	1268	1474	1646	1803	1944	2085	2211	2321	2540	2760	2947	3120	3293	3450	3606
16	962	1352	1659	1925	2150	2355	2539	2724	2888	3031	3318	3605	3850	4075	4301	4406	4710
18	1218	1710	2099	2436	2722	2981	3214	3447	3662	3836	4199	4562	4873	5158	5443	5702	5962
20	1504	2112	2592	3008	3360	3680	3968	4256	4512	4736	5184	5632	6016	6368	6720	7040	7360
22	1820	2552	3136	3640	4065	4452	4801	5149	5459	5730	6272	6814	7279	7705	8131	8518	8905
24	2163	3046	3737	4331	4838	5299	5712	6128	6496	6828	7465	8108	8663	9168	9676	10144	10598
30	3384	4752	5832	6768	7560	8280	8928	9576	10152	10656	11664	12672	13536	14328	15120	15840	16560

d = diameter of pipe in inches.
L = length in yards.
H = head in feet.
G = gallons per minute.

$$\frac{(3d)^5 \times \mathrm{H}}{\mathrm{L}} = \mathrm{G}^2.$$

$$\frac{\mathrm{G}^2 \times \mathrm{L}}{(3d)^5} = \mathrm{H}.$$

$$\frac{\mathrm{G}^2 \times \mathrm{L}}{\mathrm{H}} = (3d)^5.$$

$$\frac{(3d)^5 \times \mathrm{H}}{\mathrm{G}^2} = \mathrm{L}.$$

These rules can be worked only by logarithms, but the friction being simply proportional to the length, we have calculated Table III., by which any problem in the friction of water-mains may be solved by multiplication or division.

(6) 1st. Having G, L, and d given, to find H. In the table opposite the given number of gallons, and under the given diameter, is found the head due to a length of one yard, and multiplying that number by the given length in yards, the product is the required head of water in feet. Thus, the head to deliver 250 gallons per minute by an 8-in. pipe 7000 yards long, will be ·00785 × 7000 = 54·95 feet.

(7) 2nd. To find d, having H, L, and G given. Divide the given head by the given length, and the nearest number thereto in the table opposite the given number of gallons will be found under the required diameter. Thus, the diameter for 320 gallons, 20 ft. head and 1600 yards long, $\frac{20}{1600} = {\cdot}0125$, the nearest number to which in the table (0128614) is found under 8 inches, the diameter sought. In most cases the tabular number will not be the exact one desired, which will only show that the true diameter is an odd size, between the standard ones in the table. But by the former rule (6) this can easily be checked. Thus in our case the true head for 8-inch pipe would be ·0128614 × 1600 = 20·578 feet, instead of 20 feet; but of course 8 inches is near enough in most cases.

(8) 3rd. To find G, having H, L, and d given. Divide the given head by the given length, and the nearest number thereto in the table, under the given diameter, will be found

opposite the required number of gallons. Thus to find the discharge of a 10-inch pipe 3000 yards long, with 40 feet head, we have $\frac{40}{3000} = \cdot 01333$; and looking for this under 10-inch diameter, we find the nearest to be ·01384, opposite 580 gallons, the discharge sought.

(9) 4th. To find L, having H, G, and *d* given. Divide the given head, by the head for one yard, found in the table under the given diameter, and opposite the given number of gallons, and the result is the required length. Thus to determine the length of 4-inch main to consume 12 feet head with 130 gallons per minute, we find under 4-inch, and opposite 130 gallons, ·067921 the head for one yard, and $\frac{12}{\cdot 067921} = 176$ yards, the length sought.

(10) To avoid a needless extension of the table, we have given only the principal numbers from 1 to 90 gallons, and from 1000 to 100,000 gallons, leaving the blanks to be supplied from the general body of the table. It will be observed that the head for 1 gallon, 10 gallons, 100 gallons, are the same, except for the position of the decimal place, which the skeleton table will fix correctly. Thus to find the discharge of 3-inch pipe 800 yards long with 17 feet head, we have $\frac{17}{800}$ ·02125, which, by skeleton table, is somewhere between 30 and 40 gallons. Now, looking in the body of the table for the same figures (neglecting the position of the decimal place), we find the nearest to be 219622, opposite 360 gallons; 36 gallons is therefore the true discharge. Again, say we required the head for 3800 gallons by a 15-inch pipe 1400 yards long. 3800 gallons is not found in the table, but 380 gallons is, and taking out the multiplier for that, and checking the decimal place by the nearest number (4000) in the skeleton table, we get $\cdot 0782532 \times 1400 = 109 \cdot 55$ feet head, &c.

(11) The illustration 3rd (8) to find G may be extended, so as to give a general view of the discharge of different sized pipes, with the same length and head. Thus we found the tabular number for 3000 yards long and 40 feet head to be $\frac{40}{3000} = \cdot 01333$, and looking for this successively under different diameters, we find that

A 6-inch pipe discharges 160 gallons per minute.
7 " " 235 " "
8 " " 330 " "
9 " " 440 " "
10 " " 580 " "
12 " " 900 " " &c.

(12) To the head found by the preceding rules, that due to the velocity of entry, as given by Table II., has in all cases to be added; but for long pipes this is so small in proportion to the head due to friction, that it may in many cases be neglected. Thus we found that the friction of an 8-inch pipe, 7000 yards long, with 250 gallons, was 54·95 feet; by Table II. it will be seen that the head due to the velocity is a little more than one inch, so that in such a case it may be neglected. But where a pipe is short, the head due to velocity may be much greater than that due to friction, and the most serious errors may be made by neglecting it. Say we had an 18-inch pipe 20 yards long, discharging 3000 gallons. By Table III. the friction is $·0196 \times 20 = ·392$ feet, and the head due to velocity by Table II. is 6 inches, or ·5 foot, being more than that due to friction; so that the total head is $·392 + ·5 = ·892$ feet. Table II. gives the utmost facility for making these calculations of head due to velocity, which should never be overlooked in cases where the pipe is short.

(13) *Bends.*—There is another source of loss of head in pipes—namely, change of direction, or bends. The best formula for calculating this loss is that of Weisbach:—

$$H = \frac{\phi}{180} \times \left\{ ·131 + 1·847 \left(\frac{r}{R}\right)^{\frac{7}{2}} \right\} \times \frac{V^2}{2g}.$$

In which H = the head due to change of direction.
r = the radius of the bore of the pipe.
R = the radius of the centre line of the bend.
V = the velocity of discharge, in feet per second.
ϕ = the angle, in degrees.

Table IV. gives by inspection the loss of head by bends of ordinary radius, such as are usually met with in practice. This may vary a little with different makers, but not so much as to affect the result seriously. Fig. 8 gives the proportion of the 8-inch bend as an illustration. But frequently much quicker bends than these have to be used in special cases, and to meet such cases some founders make quick bends, of the proportions given in Table IV., and shown by Fig. 9, which

TABLE IV.—Table for Bends in Water Pipes, showing the loss of Head due to change of Direction by one Bend of 90°.

Diameter of the Pipe in Inches.	Radius of Centre line of Bend in Inches.	HEAD OF WATER IN INCHES LOST BY ONE BEND OF 90°.														
		$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{2}$	2	3	4	5	6	9	12	18	24
		GALLONS DISCHARGED PER MINUTE.														
2	12	25	36	51	63	73	81	103	126	146	163	179	219	252	309	358
3	12	58	83	117	144	166	203	235	288	332	371	407	498	576	705	814
4	12	102	145	205	252	291	356	411	504	582	650	713	873	1008	1233	1426
5	18	162	229	324	396	458	561	648	793	916	1024	1122	1374	1586	1944	2244
6	18	232	328	464	568	656	803	928	1136	1312	1467	1607	1968	2272	2784	3124
7	18	309	437	618	757	874	1070	1236	1514	1748	1954	2141	2622	3028	3708	4282
8	18	402	568	804	985	1137	1393	1608	1970	2274	2542	2786	3411	3940	4824	5572
9	18	501	709	1002	1228	1418	1737	2005	2456	2836	3170	3474	4254	4912	6015	6948
10	18	606	857	1212	1484	1714	2100	2424	2968	3428	3832	4199	5142	5936	7272	8398
12	21	866	1225	1733	2122	2451	3003	3466	4245	4902	5480	6005	7353	8490	10398	12010
15	24	1317	1864	2635	3228	3728	4567	5271	6457	7456	8336	9134	11184	12914	15813	18268
18	27	1857	2626	3714	4549	5253	6435	7428	9098	10506	11745	12870	15759	18196	22284	25740
21	30	2467	3490	4935	6044	6980	8550	9870	12089	13960	15607	17100	20940	24178	29610	34200
24	33	3165	4477	6330	7754	8954	10968	12661	15508	17908	20021	21937	26862	31016	37983	43870
		TABLE FOR QUICK BENDS.														
2	3	23	32	46	56	65	79	92	112	130	145	159	195	214	276	318
3	$3\frac{1}{2}$	44	63	89	109	126	154	178	218	252	282	309	378	436	534	618
4	4	69	98	139	170	197	241	278	341	394	440	480	591	682	834	966
5	$4\frac{1}{2}$	96	136	172	236	272	333	385	472	544	608	666	816	944	1155	1332
6	5	128	181	256	314	362	443	512	629	724	809	886	1086	1258	1536	1774
7	$5\frac{1}{2}$	161	229	322	396	458	561	645	793	917	1024	1122	1374	1586	1935	2244
8	6	199	281	398	487	563	689	796	975	1126	1259	1379	1689	1950	2388	2758

illustrates the proportions of a quick 5-inch bend. The formula used for calculating the table is a modification of that of Weisbach:—

$$V^2 = \frac{2\,g\,H}{\frac{\phi}{180} \times \left\{ \cdot131 + 1\cdot847 \left(\frac{r}{R}\right)^{\frac{7}{2}} \right\}}$$

If the whole be taken in feet, then $2g = 64$; but it is perhaps most convenient to take H in inches and V in feet, in which case $2g = 5\cdot333$. This table requires little explanation; but it will be seen that an ordinary 8-inch bend with 18-inch radius consumes 3-inch head when passing 1970 gallons per minute; but a quick 8-inch bend with 6-inch radius consumes 12-inch head with the same quantity. Again, in a 4-inch pipe carrying 100 gallons, each ordinary bend causes a loss of $\frac{1}{8}$th inch of head, but a quick bend loses $\frac{1}{4}$th inch. The table is arranged for bends of 90°, or quarter bends, as they are technically named, but is applicable for any other angle. The loss of head is simply proportional to the angle. Thus a half-quarter bend of 45°, or one-eighth part of a circle, consumes half the head of a bend of 90°; and a bend of 180°, or half a circle, takes double.

(14) When a long main is composed of pipes of different sizes, as is very frequently the case, the head for each must be separately calculated, and the sum total taken. Thus, if we required 300 gallons per minute through a main 1200 yards long, composed of 800 yards of 7-inch, 300 yards of 6-inch, and 100 yards of 5-inch pipe, the head would be—

By Table III. Length.
300 gallons 7-inch = ·022 × 800 = 17·6 feet head.
„ 6 „ = .0476 × 300 = 14·28 „
„ 5 „ = ·1185 × 100 = 11·85 „

43·73 feet total.

If there were bends in the pipes, we must add the head for them from Table IV. Say we had

4 common bends in 7 inch each $\frac{1}{8}$-inch head = $\frac{1}{2}$ inch.
3 quick „ 7 „ $\frac{1}{2}$ „ = $1\frac{1}{2}$ „
2 common „ 6 „ $\frac{1}{4}$ „ = $\frac{1}{2}$ „
2 quick „ 6 „ $\frac{3}{4}$ „ = $1\frac{1}{2}$ „
4 common „ 5 „ $\frac{1}{2}$ „ = 2 „
3 quick „ 5 „ $1\frac{1}{2}$ „ = $4\frac{1}{2}$ „

Total $10\frac{1}{2}$ inches.

Thus, even for such a large number of bends, the loss of head is only 10½ inches, or ·875 of a foot; so that the total head is 43·73 + ·875 = 44·605 feet.

(15) When with such a series of pipes the head is given, and the discharge has to be determined, the case does not admit of a direct solution; but we must apply a useful general law, which may be stated as follows:—"*The discharge through any pipe, or series of pipes, is nearly proportional to the square root of the head;*" and this is true in a pipe with bends, jets, contractions, &c. Say we required the discharge with 30 feet head, by a main 2100 yards long, composed of 1200 yards of 8-inch pipe with four common bends, 700 yards of 6-inch pipe and three bends, and 200 yards of 5-inch pipe with two common and two quick bends. The first thing to be done is to assume a discharge, and calculate the head for it, as was done in the last example. It is unimportant whether the assumed quantity is near the true discharge or not, or whether it is too much or too little. Say in our case we take it at 400 gallons. Then

		By Table III.		Length.		Feet.	
400 gallons	8-inch pipe	= ·02	×	1200	=	24·0	head.
„	6 „	= ·085	×	700	=	59·5	„
„	5 „	= ·21	×	100	=	21·0	„
						104·5	

	In.		In.		Bends.		In.	
4 common bends	8	each	⅛	×	4	=	½	head.
3 „	6	„	½	×	3	=	1½	„
2 „	5	„	¾	×	2	=	1½	„
2 quick „	5	„	3	×	2	=	6	„
							9½	= ·8 foot.

Total 105·3 head.

Thus we find that for 400 gallons we require 105·3 feet head instead of 30 feet, the head given; then by the rule (15) $\dfrac{\sqrt{30} \times 400}{\sqrt{105{\cdot}3}}$, or $\dfrac{5{\cdot}447 \times 400}{10{\cdot}26} = 213$ gallons, the real discharge sought. Further illustrations of this subject will be found in the chapter on Fountains.

(16) The contour of the section of the line of pipes is a

matter of some importance. The best condition, when the pipe is of uniform diameter from end to end, is of course a uniform slope throughout. This, however, can rarely be obtained, the pipe having to follow the contour of the ground, as in Fig. 28. If a number of open topped pipes were inserted anywhere along the main, as at A, B, C, D, &c. &c., the water would rise in them to the level of the oblique line J K, which, in the case of a pipe of the same bore from end to end, would be a straight line, as shown. This line is termed the *hydraulic mean gradient.*

(17) When, as in Fig. 30, the pipes are of different diameters, then each would have its own gradient, showing at every point the loss of head due to that particular pipe as in the figure. No loss of effect will arise from the pipe following the section of the ground, *so long as the contour of the pipe does not anywhere along the line, rise above the hydraulic mean gradient,* except, indeed, a slight loss from the increase of length due to the departure from the straight line. Thus, in Fig. 28, where the ground is much broken, but does not anywhere rise above the gradient, the discharge will be the same as by a pipe of uniform slope.

(18) But if, as in Fig. 29, a hill as at B rises higher than the gradient, then the pipe from C to D will be in a state of partial vacuum, air will be given out by the water and will accumulate at the summit, and being driven forward by the water from C to B, will remain permanently in the pipe from B to G, occupying the upper part of the pipe, while the water trickles down the lower half of the pipe as in a trough or channel, and the vertical head from B to G is lost, the hydraulic gradient being now from A to B, from B to G, and from G to F, this last being parallel to that from A to B, or at the same angle with the horizon. The discharge at F will therefore be, not the amount due to the head E F on the length A F, but that due to the head E B on the length A B.

(19) In this case the pipe from A to B should be of large diameter, so as to deliver at B the required quantity with the head E B; and the pipe from B to F may be of smaller diameter, so as to deliver the same quantity at F with the head H F. Say we take a case with the length A F = 5000 yards, the head E F 90 feet; and that the length A B = 2400 yards and the head E B 10 feet, and that 500 gallons were required at F. With uniform slope we should have required

$\frac{90}{5000}=018.$ which by Table III = a 9-inch pipe or rather less, for a 9-inch pipe would deliver 500 gallons with ·017425 × 5000 = 87·125 feet. But the delivery at B with 10-feet head with a 9-inch pipe would be $\frac{10}{2400}=\cdot004167$, by table = 245 gallons only instead of 500; and of course this is all we should get at F with such an arrangement. The pipe from A to B should be $\frac{10}{2400}=\cdot004167$, by Table III. a 12-inch pipe; and the pipe from B to F may be $\frac{80}{2600}=\cdot03077$ = an 8-inch pipe by table. We may check these results thus:—

	By Table III.	Length.	Head.
12-inch pipe, 500 gall. =	·00413 ×	2400 =	9·912 feet.
8 „ 500 „ =	0314 ×	2600 =	81·64 „
			91·552

Thus we find the exact head to be a little more than the head at disposal, but in most cases the agreement is near enough.

(20) When a long main is composed of different sizes of pipes, and passes over uneven ground, the best course is to draw the gradients on the section of the pipes, so as to see at a glance that none of the hill-tops rise above them. Fig. 30 is a case in which, with a fall of 240 feet, we have a 10-inch main 4000 yards long; an 8-inch main 3000 yards; and a 6-inch main 2000 yards long. To divide the given fall in the proper proportion between the different pipes, and so find the gradients, let us assume that 100 gallons are delivered at D; then

	By Table.	Length.	
100 gall. 10-inch =	·000411 ×	4000 =	1·644 feet head.
„ 8 „ =	·001256 ×	3000 =	3·768 „
„ 6 „ =	·005292 ×	2000 =	10·584 „
			15·996 total head.

Then

E B, or the true head for the 10-inch = 15·996 : 240 :: 1·644 : 24·678
F C „ 8 „ = 15·996 : 240 :: 3·76 : 56·443
G D „ 6 „ = 15·996 : 240 :: 10·584 : 158·879

240·000

We can now draw the gradients on the section as in Fig. 30, and then, if the contour of the ground is below them throughout, all is well.* The discharge at D may be calculated from any one of the pipes: say we take the 8-inch; then $\frac{56{\cdot}443}{3000} = {\cdot}01884$ = about 386 gallons by Table III.

(21) There are many questions for the solution of which no general rules can be given—they require reasoning with the assistance of rules. The following cases may be useful. Say we require in Fig. 34, 50 gallons at B and 100 gallons at A, and have to determine the sizes of the mains. If we assume 3 inches for E, the head will be $\cdot 04235 \times 160 = 6{\cdot}776$ feet; so that the pressure at C will be 18—10 +6·776=14·776 feet; therefore the head above A on the pipe F will be 25—18+14·776=21·776, and the necessary pipe with that head will be $\frac{21{\cdot}776}{250} = {\cdot}0871$ = a 3½-inch pipe by Table III. The pipe D has to carry 150 gallons with 3·224 feet head (18—14·776), and we have $\frac{3{\cdot}244}{300} = {\cdot}010814$ = 6 inch pipe by table.

300
= ·0107

(22) Take another case shown by Fig. 33, and say that we required the head at D to deliver 600 gallons at E by the double pipes, and also to find what proportion of the 600 gallons passes by the two branches A C B and A B. Let us assume that the pipe A C B carries 100 gallons; then the head at A for that quantity would be—

			Head.
100 gall. 12-inch pipe	= ·00016538	× 1100	= ·181918 feet.
,, 9 ,,	= ·000697	× 800	= ·557600 ,,
			·739518 ,,

and with that head at A the pipe A B would at the same time deliver $\frac{\cdot 739518}{950} = {\cdot}000778$ = 79 gallons by table; so that the two sets of pipes deliver at B 179 gallons with a head of ·739518 feet, and therefore (15) to deliver the 600 gallons required would take $\frac{\cdot 739518 \times 600^2}{179^2} = 8{\cdot}3$ feet. The 12-inch pipe from D to A would require for 600 gallons ·00595 × 1100 = 6·545 feet head, and the 9-inch from B to E

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* The principle of this method of calculating a series of gradients is due to C. E. Amos, Esq., of The Grove, Southwark.

TABLE VI.—Experiments on Jets by Weisbach.

Head on Jet in Feet.	Diameter of Jet in Inches.	
	⅜	⅝
	Height of Jet in Feet.	
3	2·865	2·844
6	5·712	5·700
9	8·541	8·559
12	11·304	11·424
15	14·040	14·250
18	16·704	17·082
21	19·278	19·845
24	21·768	22·560
27	24·138	25·218
30	26·43	27·810
33	28·611	30·338
36	30·708	32·724
39	32·643	35·022
42	34·440	37·254
45	36·180	39·420
48	37·776	41·424
51	39·219	43·299
54	40·608	45·090
57	41·838	46·740
60	42·960	48·360

TABLE VII.—Of the Height of Jets with Different Heads.

Head on Jet in Feet.	Diameter of Jet in Inches.										
	⅛	¼	⅜	½	⅝	¾	1	1¼	1½	1¾	2
	Height of Jet in Feet.										
10	8·75	9·37	9·6	9·7	9·75	9·8	9·84	9·875	9·9	9·91	9·92
20	15·0	17·5	18·33	18.75	19·0	19·2	19·4	19·5	19·6	19·6	19·7
30	19·0	24·4	26·6	27·2	27·75	28·3	28·6	29·0	29·1	29·2	29·3
40	20·0	30·0	33·3	35·0	36 0	37·0	37·5	38·0	38·3	38·6	38·7
50		34·4	39·6	42·2	44·0	45·0	46·1	47·0	47·4	47·8	48·0
60		37·5	45·0	48·7	51·0	52·0	54·4	55·0	56·2	58·6	57·0
70		39·0	50·0	55·0	58·0	60·0	62·4	64·0	65·0	65·6	66·0
80		40·0	53·0	60·0	64·0	67·0	70·0	72·0	73·3	74·2	75·0
90			56·0	65·0	70·0	73·0	77·0	80·0	81·6	83·0	84·0
100			58·0	69	75	79	84	87	90	91	92
120			60·0	75	84	90	97	102	105	107	109
140				79	91	99	109	116	120	123	125
160				80	96	106	120	128	133	137	140
180					99	112	129	139	141	151	155
200					100	116	137	150	158	166	169
220						119	145	159	165	177	182
240						120	150	168	180	189	195
260							155	175	190	200	208
280							158	182	198	210	219
300							160	187	206	220	230
350								198	222	241	255
400								200	233	257	275

$\cdot025092 \times 400 = 10\cdot037$ feet, and the total head at D will be $6\cdot545 + 8\cdot3 + 10\cdot037 = 24\cdot882$ feet. The pipe A C B will carry $\frac{600 \times 100}{179} = 336$ gallons. Consequently the pipe A B will take the rest, or 264 gallons.

(23) Table III. gives the greatest possible facility for the calculation of pipe questions, as may be seen in the examples we have given, and for all ordinary cases the results are correct; but for very small velocities with low heads, say under one foot, experiment has shown that the discharges are less than that table would give, and for such cases Prony's more difficult and laborious rule seems to give the most correct result. Table V. has been calculated by the following modification of Prony's rule: $\frac{(V + \cdot0816)^2 - \cdot00665}{196\cdot24} = D\ S$, in which $V =$ the velocity of discharge in feet per second, D the diameter of the pipe in inches, and $S =$ the slope, or $\frac{H}{L}$, H being the head and L the length, both in the same terms, which for very small heads may be most conveniently in inches. Table V. is only calculated for small velocities, because the Table III. gives the same results at moderate velocities, and is much more facile in application. We have added opposite each velocity the corresponding discharge of different-sized pipes, from 1½-inches to 24-inches diameter, so as to abridge the labour as much as possible.

(24) 1st. To find the head, having G, L, and *d* given. In Table V., under the given diameter, find the nearest number of gallons, and take from column 1 the number opposite to it, which, multiplied by the length in inches, and divided by the diameter of the pipe in inches, will give the required head in inches. 2nd. To find the discharge, having L, H, and *d* given. Multiply the given head in feet by the diameter in inches, and divide by the length in feet, and find the nearest number thereto in column 1. Then opposite to that, and under the given diameter, is found the discharge in gallons per minute.

(25) Let us take an extreme case. Say we require the head for a 10-inch pipe 1000 yards long, discharging 20 gallons per minute. The nearest number under 10 inches diameter is 20·45 gallons, opposite which, in column 1, is found ·0001341,

TABLE IX.—Of the Discharge of Jets with Different Heads.

Head on Jet in Feet.	DIAMETER OF JET IN INCHES.																
	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$
	GALLONS DISCHARGED PER MINUTE.																
5	·537	1·21	2·15	3·36	4·83	6·58	8·59	13·4	19·3	26·3	34.4	53·7	77·0	105	137	174	215
10	·758	1·71	3·03	4.74	6·82	9·30	12·1	18·9	27·3	37·1	48·5	75·8	109	148	194	244	303
15	·929	2·09	3·72	5·81	8·36	11·4	14·8	23·2	33·4	45·5	59·4	92·9	134	182	238	301	372
20	1·07	2·41	4·29	6·70	9·66	13·0	17·2	26·8	38·6	52·6	68·6	107	154	210	274	347	429
25	1·20	2·70	4·80	7·50	10·8	14·7	19·2	30·0	43·2	58·8	76·8	120	173	235	307	389	480
30	1·31	2·95	5·25	8·21	11·8	16·1	21·0	32·8	47·3	64·4	84·1	131	189	258	336	426	525
35	1·42	3·19	5·68	8·87	12·8	17·4	22·7	35·5	51·1	69·6	90·9	142	204	278	364	460	568
40	1·52	3·41	6·07	9·48	13·6	18·6	24·7	37·9	54·6	74·3	97·1	152	218	297	388	491	609
45	1·61	3·62	6·44	10·1	14·5	20·2	25·8	40·3	58·0	80·7	103	161	232	323	412	522	644
50	1·70	3·82	6·79	10·6	15·2	21·3	27·1	42·4	61·1	84·9	109	170	244	340	434	550	680
60	1·86	4·18	7·44	11·6	16·7	22·8	29·7	46·4	66·9	91·1	119	186	267	364	476	602	744
70	2·01	4·52	8·03	12·5	18·1	24·5	32·1	50·1	72·3	98·4	129	201	289	393	514	650	803
80	2·14	4·83	8·58	13·4	19·3	26·3	34·3	53·6	77·2	105	137	215	309	421	549	695	858
90	2·27	5·12	9·10	14·2	20·5	27·9	36·4	56·9	82·0	111	145	227	328	446	593	738	910
100	2·40	5·40	9·6	15·0	21·6	29·4	38·4	60·0	86·4	117	153	240	346	471	615	778	960
110	2·52	5·66	10·1	15·7	22·6	30·9	40·3	62·9	90·6	123	161	252	362	493	644	815	1010
120	2·63	5.91	10·5	16·4	23·6	32·6	42·0	65·7	94·6	130	168	263	378	522	673	852	1052
130	2·73	6·15	10·9	17·1	24·6	33·5	43·7	68·4	98·5	134	175	273	394	536	700	886	1094
140	2·84	6·39	11·3	17·7	25·5	34·8	45·4	71·0	102	139	181	284	409	557	727	920	1136
150	2·94	6·61	11·7	18·4	26·4	36·0	47·0	73·5	106	144	188	294	423	576	752	952	1176
175	3·17	7·14	12·7	19·8	28·5	39·0	50·8	79·4	114	156	203	317	457	624	813	1029	1270
200	3·39	7·63	13·5	21·2	30·5	41·5	54·3	84·8	122	166	217	339	490	665	869	1099	1358
250	3·79	8·53	15·1	23·7	34·1	46·5	60·7	94·8	136	186	243	379	546	744	971	1230	1518
300	4·15	9·35	16·6	25·9	37·4	50·1	66·5	104	149	204	266	415	598	816	1064	1346	1663

which, multiplied by the length in inches (36000), and divided by the diameter of the pipe also in inches, will give the head in inches, thus: $\frac{\cdot 0001341 \times 36000}{10} = \cdot 482$ inches. We may compare this with Table III., by which the head comes out $\cdot 00001646 \times 1000 = \cdot 01646$ feet, or ·19752 inches only; so that in this extreme case Prony's rule gives nearly 2½ times the head by Table III. But in ordinary cases the two tables give nearly the same result. Thus, say we have a 6-inch pipe, 2000 yards long, with 10 feet head; then $\frac{H \times d}{L}$ is in that case $\frac{10 \times 6}{2000 \times 3} = \cdot 01$, the nearest number to which in Table V. is ·010407 or ·009694, opposite to which, under 6 inches diameter, are respectively 99·4 and 95·7 gallons, the mean of which may be taken in this case at 97·5 gallons. Now, by Table III. the discharge is $\frac{10}{2000} = \cdot 005$, which may be estimated at 97·5 gallons also, so that the two tables in this case give the same result. If, however, we calculate the discharge of the same pipe with a very small head, say 6 inches, we have by Prony's table V. $\frac{H \times d}{L}$ or $\frac{6 \times 6}{72000} = \cdot 0005$, which may be taken at 17½ gallons; but by Table III. the discharge will be $\frac{\cdot 5}{2000} = \cdot 00025 = 21 \cdot 8$ gallons, so that in this case the difference is considerable; in most cases, Table III. is correct enough for practice, with heads over 1 or 2 feet.

Fountains.—(26) When water issues from a jet as at J, Fig. 16, it should theoretically attain the height of the head, and h should be equal to H; but it has been found by experiment that the height of the jet is always less than the head—a loss arising from the resistance of the air. The difference, or h^1, increases with the absolute height of the jet, and becomes less with increase in the diameter. There are very few reliable experiments on this subject, and the laws indicated by those we have are very intricate. The best experiments we have are those of Weisbach, with jets $\frac{3}{8}$ and $\frac{5}{8}$-inch diameter. The results are given by Table VI.; and from these and some other experiments we find that h^1 increases nearly in the ratio of the square of the height of the jet, so that if we plot the successive heights given by experiment as in Fig. 17, we obtain a curve which approximates to a parabola; thus for a $\frac{1}{2}$-inch jet as in the Figure, with 160 feet head, the jet would have attained the height B, or 160 feet, if there had been no resistance from the air; but it is found by experiment that it only reaches 80 feet as at D, therefore $h^1 = 80$ feet is lost. Again, with 80 feet head, the jet would have reached $C = 80$ feet; but the experimental height is 60 feet, and in this case $h^1 = 20$ feet.

(27) If we do this for different diameters of jets, we shall find that, with the same head, h^1 varies nearly in inverse ratio to the diameter; for instance, we have seen that with 80 feet head on a $\frac{1}{2}$-inch jet 20 feet is lost. Then for a jet 1 inch diameter the loss would be about 10 feet, and the height attained 70 feet; but with a $\frac{1}{4}$-inch jet the loss would be about 40 feet, and the height attained 40 feet, and thus we have the elements for calculating the loss for any case, not perfectly agreeing, perhaps, with the true law, but the best approximation we can obtain. This is a subject on which more experimental information is very desirable. Table VII. gives the height of jets with different heads, and is calculated by the rule $h^1 = \frac{H^2}{d} \times \cdot 0125$, in which h^1 is the difference between the height of the jet and that of the head upon it, $H =$ the head on the jet, and $d =$ the diameter of the jet in $\frac{1}{8}$ths of an inch.

(28) It will be found by the foregoing rule that each particular size of jet attains its *maximum* height with a certain head, and that if the head is increased beyond that point, the height of the jet is not increased thereby, but is actually diminished. This appears paradoxical; but an excessive head breaks the jet into spray, and it meets with more resistance than a jet of solid water issuing with a moderate head. Some experiments with excessive heads show an enormous loss. A jet, 1 inch diameter, with 427 feet head, reached a height of about 109 feet, as measured by a theodolite. Our rule gives the loss h^1 at 285 feet, and hence the height of jet $427 — 285 = 142$ feet. The error of 33 feet is considerable, but perhaps not more than might be expected for such an extreme case. Our table shews that this same size of jet would have attained a height of 160 feet with 300 feet head; so that, with an increase of head, we obtain

a less height of jet. A jet 1¼ inch diameter attained a height of 144 feet with 300 feet head; our table gives 187 feet. A jet 1½ inch diameter reached a height of 154 feet with 185 feet head; our table gives 146 feet.

TABLE VIII.

A.	B.	C.	D.
¼ inch	·45 inch	·6 inch	·3 inch
⅜	·67	·9	·45
½	·90	1·2	·6
⅝	1·12	1·5	·75
¾	1·35	1·8	·9
1	1·80	2·4	1·2
1¼	2·25	3·0	1·5
1½	2·70	3·6	1·8
1¾	3·15	4·2	2·1
2	3·6	4·8	2·4
2¼	4·0	5·4	2·7
2½	4·5	6·0	3·0
2¾	4·9	6·6	3·3
3	5·4	7·2	3·6

(29) The quantity of water discharged may be calculated from the velocity found by the formula $\sqrt{H} \times 8 = V$ (1), or more directly by $\sqrt{H} \times d^2 \times \cdot 2547 = G$, in which $H =$ the head on the jet in feet, d the diameter in $\frac{1}{8}$ths of an inch, and $G =$ gallons discharged per minute. But this quantity is never fully realised in practice, except d be taken to represent the diameter of the contracted vein (3), or otherwise that the jet nozzle has the form of the vena-contracta.

(30) The form of nozzle is a matter of importance, not only as affecting the quantity discharged, but also the solidity of the issuing column of water. Fig. 25 shows the best form of nozzle, the lip at E, projecting beyond the mouth, is intended to protect the bore from indentation by accident, &c. Table VIII. gives the general proportions for different sizes. The discharge by such nozzles is about ·943, the theoretical being 1·0, and may be found direct by the formula $\sqrt{H} \times d^2 \times \cdot 24 = G$, and by this rule we have calculated Table IX.

(31) When a jet is placed at the end of a pipe, or series of pipes, as is usually the case, calculation must be made of the loss of head by friction in such pipes, so as to obtain the actual head *on the jet*, for which alone the rules and tables apply. Say, for illustration, we take the case shown by Fig. 1 of a jet 1 inch diameter, 70 feet high, at the end of a main 6 inch, 5 inch, and 4 inch diameter of the lengths given, and that we have to calculate the head necessary. Table VII. shows that a jet 1-inch diameter, 70 feet high, requires 80 feet head; and Table IX. gives the discharge of the same jet, with 80 feet head, at 137 gallons per minute. Then by Table III. we calculate the friction of the main, and we have the following results:—

Head to play 1-inch jet 70 feet high . . 80·00 feet
Friction 6-inch main, say 140 galls. = ·01037 × 600 = 6·22 „
„ 5 „ „ ·0258 × 300 = 7·74 „
„ 4 „ „ ·0788 × 100 = 7.88 „
101·84 feet

(32) In other cases we may have the head and diameter of pipes and jet given, and have to determine the discharge. This case is illustrated by Fig. 2, and we must follow the course indicated in (15). Say we assume the discharge at 300 gallons, Table IX. shows that for that quantity a jet 1½ inch diameter will require about 75 feet head. Then by Table III. we find the friction of the main as follows:—

Head to play 1½-inch jet 300 gallons . . 75·00 feet
Friction 7-inch main 300 gallons = ·022 × 800 = 17·60 „
„ 6 „ „ ·0476 × 400 = 19.04 „
„ 5 „ „ ·1185 × 80 = 9·48 „
121·12 feet

So that, for our assumed discharge of 300 gallons, we require only 121·12 feet instead of 150, the head at disposal. Then by the rule (15) the true discharge, with 150 feet, will be $\dfrac{300 \times \sqrt{150}}{\sqrt{121\cdot16}} = 334$ gallons.

(33) In another case we might require to find the diameter of one of the main pipes; having all the rest given, say that we have to find the diameter of the pipe P, in Fig. 3.

Table VII. gives a head of 90 feet for 1¼-inch jet 80 feet high; and Table IX. gives 227 gallons for the discharge.

Then 1¼-inch jet 80 feet high	90·0 head.
Friction of 6-inch main, ·028 × 400 . . .	11·2 ,,
	101·2 head.

Leaving 115—101·2 = 13·8 feet for the friction of the pipe P, and $\frac{13 \cdot 8}{200} = \cdot 069$ per yard (7); which, by Table III., is equal to a 5-inch pipe, with say 230 gallons, and this is the required diameter of P.

(34) When the discharge takes place obliquely, or out of the perpendicular, the path of the jet is a parabola, and may be conveniently described by the method shown by Fig. 23, in which we have a jet discharging upward at an angle of 45°, and with a head of 14 feet, which, by Table X., will give a velocity of 30 feet per second, or 3 feet per tenth of a second; and if we mark a series of points A B C, &c., 3 feet apart, they will show the position of a particle of water each tenth of a second if gravity does not act; but of course gravity does act simultaneously, and Table XI. gives the space fallen through each tenth of a second, which, being plotted on the perpendiculars drawn through each of the points A B C, &c., will give the true position of the particle at each tenth of a second. Thus, in $\frac{3}{10}$ths of a second it would have arrived at C if uninfluenced by gravity, but the table shows that in that time a body falls 1 foot 5¼ inches, consequently F is the true position at that moment, and so of the rest. The Figure gives the path for 2 seconds. The curve S T, Fig. 23, shows the path of a jet, with the same head and velocity, projected *downwards*, at the same angle of 45°. Fig. 19 gives the path for a horizontal projection, and also illustrates another method of drawing the parabolic curve, which consists in dividing the total space fallen through J K into the same number of equal parts as the line H J, and drawing radial lines from the point H, as shown. The path of the jet is through the intersections of the radial lines with the perpendiculars, as shown. The two methods give the same result precisely, and may be used indifferently.

(35) There are some general laws in parabolic paths of jets which it will be well to state distinctly. Fig. 20 gives a jet

TABLE X.

FALLING BODIES, giving the Space fallen through to acquire certain Velocities.

Velocity in Feet per Second.	Space.		Velocity in Feet per Second.	Space.		Velocity in Feet per Second.	Space.	
	feet.	inch.		feet	inch.		feet.	inch.
1	0	$0\frac{3}{16}$	21	6	10	41	26	1
2	0	$0\frac{3}{4}$	22	7	6	42	27	5
3	0	$1\frac{5}{8}$	23	8	3	43	28	9
4	0	3	24	9	0	44	30	1
5	0	$4\frac{5}{8}$	25	9	9	45	31	5
6	0	$6\frac{3}{4}$	26	10	6	46	32	10
7	0	$9\frac{1}{8}$	27	11	4	47	34	4
8	1	0	28	12	3	48	36	10
9	1	$3\frac{1}{4}$	29	13	0	49	37	4
10	1	$6\frac{3}{4}$	30	14	0	50	38	11
11	1	$10\frac{1}{2}$	31	14	11	52	42	0
12	2	3	32	15	11	54	45	4
13	2	$7\frac{1}{2}$	33	16	11	56	50	0
14	3	$0\frac{3}{4}$	34	18	0	58	52	0
15	3	6	35	19	0	60	56	0
16	4	0	36	20	1	62	59	8
17	4	6	37	21	5	64	63	8
18	5	0	38	22	6	66	57	8
19	5	7	39	23	9	68	72	0
20	6	3	40	24	11	70	76	0

TABLE XI.

FALLING BODIES.

Time, Seconds.	Whole Space fallen.		Velocity acquired. Feet per Second.
	feet.	inch.	feet.
$\frac{1}{10}$	0	$1\frac{15}{16}$	3·2
$\frac{2}{10}$	0	$7\frac{5}{8}$	6·4
$\frac{3}{10}$	1	$5\frac{1}{4}$	9·6
$\frac{4}{10}$	2	$6\frac{3}{4}$	12·8
$\frac{5}{10}$	4	0	16·0
$\frac{6}{10}$	5	$9\frac{1}{8}$	19·2
$\frac{7}{10}$	7	10	22·4
$\frac{8}{10}$	10	$2\frac{7}{8}$	25·6
$\frac{9}{10}$	12	$11\frac{1}{2}$	28·8
1	16	0	32·0
$1\frac{1}{10}$	19	$4\frac{3}{8}$	35·2
$1\frac{2}{10}$	23	$0\frac{1}{2}$	38·4
$1\frac{3}{10}$	27	$0\frac{1}{2}$	41·6
$1\frac{4}{10}$	31	$4\frac{3}{8}$	44·8
$1\frac{5}{10}$	36	0	48·0
$1\frac{6}{10}$	41	0	51·2
$1\frac{7}{10}$	46	$2\frac{5}{8}$	54·4
$1\frac{8}{10}$	51	1	57·6
$1\frac{9}{10}$	57	$9\frac{1}{8}$	60·8
2	64	0	64·0

playing obliquely from a nozzle at J, and striking the horizontal plane at G.

(36) 1st. If the line of direction of the jet pipe be prolonged, it cuts the axis of the parabola at a point, C, whose distance from the base is always double the height of the parabola, or C N is equal to twice D N. This gives a useful rule for finding the proper angle of the jet pipe when the path of the jet has been determined.

(37) 2nd. If we find the focus of the parabola by the ordinary method, namely, by bisecting the radius of the base at A, drawing the line A D and making A L perpendicular to A D, then the point L is the focus of the parabola, and the distance N L is the *extra* head, h, necessary to play the jet horizontally, or the difference between the maximum height of the jet and the head upon it at J, H being the actual height which the jet attains at D, and H^1 the total head at J, to produce the parabolic path of the jet.

(38) 3rd. If, therefore, with the same head, the jet were made to play vertically, it would (theoretically) attain the height of H^1 instead of H.

(39) 4th. In all cases h bears a certain proportion to H and B; $h = \frac{(\frac{1}{4}\,B)^2}{H}$, thus to play a jet 32 feet horizontally (B), and 16 feet high (H), as in Fig. 21, we shall have $h = \frac{8^2}{16} =$ 4 feet, which, added to the height of the jet (16 feet), gives 20 feet for the total head on the jet.

(40) 5th. The horizontal distance may be calculated from H and H^1, for $H^1 - H = h$, and $\sqrt{h \times H} = (\frac{1}{4}\,B)$; thus for $H^1 = 20$ and $H = 16$, as in Fig. 21, we have $h = 20 - 16 = 4$ feet, and the range will be $\sqrt{4 \times 16} \times 4 = 32$ feet.

(41) 6th. When the jet issues horizontally as in Fig. 18, its path is half a parabola, following the same laws as before, namely, $h = F$, also $h = \frac{(\frac{1}{2}\,P)^2}{H}$ and $\frac{(\frac{1}{2}\,P)^2}{h} = H$.

(42) In some cases the two half parabolas are unequal, as in Fig. 24, in which we have a jet 20 feet high at its maximum, and delivering at N=15 feet high, and 24 feet distant horizontally from the nozzle at J, and we require to find h=the extra head, and to describe the path of the jet. Here we

have first to find the centre line dividing the semi-parabolas, and to do this we have $\frac{D\times\sqrt{H''}}{\sqrt{H}+\sqrt{H''}}=R^1$, which in our case becomes $\frac{24\times\sqrt{5}}{\sqrt{20}+\sqrt{5}}$ or $\frac{24\times 2{\cdot}236}{4{\cdot}472+2{\cdot}236}=8$ feet; therefore the distance of the centre line from J will be 24—8=16 feet; or it may be found by $\frac{D\times\sqrt{H}}{\sqrt{H}+\sqrt{H''}}=R$; in our case $\frac{24\times 4{\cdot}472}{4{\cdot}472+2{\cdot}236}=16$ feet. Then the focus of the two parabolas may be found as before, and it will be observed that F and F^1 are equal, and in our case $h=\frac{(\frac{16}{2})^2}{20}=3{\cdot}2$ feet, or it may be found from the other semi-parabola thus: $h\ \frac{(\frac{8}{2})^2}{5}=3{\cdot}2$ feet as before. The total head at J will therefore be $20+3{\cdot}2=23{\cdot}2$ feet (H^1). If we reverse the direction of the jet, placing the nozzle at N instead of at J, and with a head of $5+3{\cdot}2=8{\cdot}2$ feet, the path of the jet will be the same as before, but the quantity of water discharged will not be the same, but will be proportional to the square roots of their respective heads, namely, 23·2 and 8·2 feet.

(43) We have followed, throughout the investigation of the path of oblique jets, the theoretical law that the height of the jet is equal to the head, and we have done this to prevent complicating the matter unnecessarily; but obviously we must apply to oblique jets the correction we found necessary for perpendicular ones; thus, if we had a jet of ½ inch diameter with 80 feet head, Table VII. shows that the height attained perpendicularly would be only 60 feet, and the path of the jet should be calculated for the latter; but the quantity of water expended, and the value of *h*, must be calculated for 80 feet.

(44) Oblique jets of great height and range deviate considerably from the true parabolic path assigned by the rules; the curve becomes, in such cases, like A D E in Fig. 22, the true parabolic path being A B C; but for moderate heights and ranges, such as usually occur in practice, the deviation is not considerable.

(45) There are many kinds of ornamental jets which may

be used with pleasing effect in *very sheltered* situations—the interior of conservatories, &c. One of these, called the "Convolvulus" from the form of its display, is shown in half-size section by Fig. 10. The pressure of a very small head of water (2 or 3 feet) raises the valve B and allows a thin sheet of water to escape, forming a sheet jet of the form given in Fig. 11, and (with the size given by Fig. 10) about 3 feet diameter, with an expenditure of about 6 gallons of water per minute. Fig. 12 is a half-sized section of the "Dome" or "Globe" jet, which produces a display of the form shown by Fig. 13, with a head of about 1 to 2 feet, the globe being about 14 inches diameter, and the expenditure of about 3 gallons per minute. With a greater head, say 3 or 4 feet, the display has the form of an umbrella about 21 inches diameter, expending about 4 gallons.

TABLE XII.—For Ball Jets.

Diameter of Jet.		Diameter of Ball.
$\frac{1}{8}$-inch	=	$1\frac{1}{8}$-inch
$\frac{1}{4}$ „	=	$1\frac{3}{4}$ „
$\frac{3}{8}$ „	=	$2\frac{1}{4}$ „
$\frac{1}{2}$ „	=	$2\frac{3}{4}$ „
$\frac{5}{8}$ „	=	$3\frac{1}{8}$ „
$\frac{3}{4}$ „	=	$3\frac{1}{2}$ „
$\frac{7}{8}$ „	=	4 „
1 „	=	$4\frac{3}{8}$ „

The basket and ball jet is another pleasing variety. The basket is of fancy wire-work, large enough to catch the ball when it escapes from the jet of water, and formed so as to return it to its place. The ball is formed of light wood (lime-tree is the best), well varnished or gilded. There is a certain proportion between the size of the ball and the diameter of the jet. As an approximation, we may give the following rule: $d^2 \times 1{\cdot}3 = D^3$, in which d = the diameter of the jet in $\frac{1}{8}$th of an inch, and D=the diameter of the ball in inches. Table XII. has been calculated by this rule; they are not often made larger than $\frac{3}{4}$-inch jet and $3\frac{1}{2}$-inch ball.

Weirs.—(46) Fig. 7 shows a weir arranged for the purpose of gauging experimentally the quantity of water passing down the stream. A is a plate of thin iron with a notch cut out of it, wide enough by estimation to carry the water with a moderate depth of overfall; this is screwed to a plank B, to obtain the requisite stiffness to the plate, and the whole is fixed in the stream as shown. A stake with a flat and level head is driven into the bed of the stream, as at C, to such a depth that the top is exactly level with the lip of the weir, and the depth of water flowing over is measured by a common rule held on its summit. The proper distance of the stake from the weir depends on the quantity of water to be dealt with;—in small weirs it may be from 2 to 3 feet, in very large ones 20 to 25 feet. The object is to place it far enough away to avoid the depression which the water suffers, as shown by Fig. 7, and to obtain the head from the true level of the water. For heads thus measured the formula may be $d \times \sqrt{d} \times 2{\cdot}67 = G$, in which d is the depth flowing over in inches, and G the gallons discharged per inch of width of weir. Table XIII. is calculated by this rule. To find the discharge of a weir, say 5 feet wide, with 3⅝-inch overfall, we have only to multiply the gallons per inch found in the table by the width in inches; in our case 18·42 × 60 = 1105·2 gallons.

(47) The table also applies to rectangular apertures discharging under a given pressure, as at Fig. 32, for the discharge in such a case is the *difference* between two weirs, A B C D and A E F D; say the head to the top of the aperture (A B) was 16½ inches, and to the bottom (A E) 22 inches, and that the width (E F) was 20 inches, then by table 22 inches = 275·5 gallons per inch, and 16½ inches = 179·0 gallons; the difference is therefore 275·5 — 179·0 = 96·5, and the discharge 96·5 × 20 = 1930 gallons.

(48) Similarly we may determine the discharge of round apertures, or approximately of any regular figures, which will not differ sensibly from that found for a circumscribing rectangular opening, reduction being made for the true area of the figure whose discharge is required. Thus, say we required the discharge of a circular aperture 12 inches diameter, the head measured from the upper edge of the orifice being 14 inches, therefore 26 inches above the lower edge. Here we have 354·0 — 139·8 = 214·2 gallons per inch wide. If the aperture were rectangular, it would therefore discharge 214·2 × 12 = 2570·4 gallons, but being circular, its area is ·7854, that of a circumscribing rectangle, and the true discharge is 2570·4 × ·7854 = 1808·8 gallons.

TABLE XIII.—Table of the Discharge of Water over Weirs, one inch wide, in Gallons per Minute.

Depth.	Galls.	Depth.	Galls.	Depth.	Galls.	Depth.	Galls.	Depth.	Galls.	Depth.	Galls.
Inch.		Inch.		Inch.		Inch.		Inch.		Inch.	
1/4	·3338	4 1/8	22·37	10	84·43	33	506·1	64	1367	95	2472
3/8	·6132	4 1/4	23·39	10 1/2	90·84	34	529·3	65	1399	96	2512
1/2	·944	4 3/8	24·38	11	97·41	35	552·8	66	1432	97	2551
5/8	1·329	4 1/2	25·49	11 1/2	104·1	36	576·7	67	1464	98	2590
3/4	1·734	4 5/8	26·56	12	111·0	37	600·9	68	1497	99	2630
7/8	2·185	4 3/4	27·64	12 1/2	118·0	38	625·4	69	1531	100	2670
1	2·670	4 7/8	28·74	13	125·1	39	650·4	70	1564	101	2711
1 1/8	3·185	5	29·85	13 1/2	132·5	40	675·5	71	1597	102	2751
1 1/4	3·818	5 1/8	30·97	14	139·8	41	700·9	72	1631	103	2791
1 3/8	4·305	5 1/4	32·12	14 1/2	147·4	42	726·7	73	1665	104	2825
1 1/2	4·905	5 3/8	33·26	15	155·1	43	752·9	74	1700	105	2873
1 5/8	5·531	5 1/2	34·44	15 1/2	163·0	44	779·3	75	1734	106	2914
1 3/4	6·167	5 5/8	35·62	16	170·9	45	806·0	76	1769	107	2955
1 7/8	6·855	5 3/4	36·85	16 1/2	179·0	46	832·8	77	1804	108	2997
2	7·552	5 7/8	38·02	17	187·1	47	860·3	78	1839	109	3039
2 1/8	8·271	6	39·24	17 1/2	195·5	48	887·9	79	1875	110	3080
2 1/4	9·011	6 1/4	41·72	18	203·9	49	915·8	80	1910	111	3122
2 3/8	9·773	6 1/2	44·25	19	221·1	50	944·0	81	1946	112	3165
2 1/2	10·55	6 3/4	46·82	20	238·8	51	972·4	82	1983	113	3207
2 5/8	11·36	7	49·45	21	256·9	52	1001	83	2019	114	3250
2 3/4	12·18	7 1/4	52·12	22	275·5	53	1030	84	2056	115	3293
2 7/8	13·02	7 1/2	54·84	23	294·4	54	1060	85	2093	116	3336
3	13·87	7 3/4	57·61	24	313·9	55	1089	86	2130	117	3379
3 1/8	14·75	8	60·41	25	333·8	56	1119	87	2162	118	3422
3 1/4	15·64	8 1/4	62·54	26	354·0	57	1149	88	2204	119	3466
3 3/8	16·55	8 1/2	66·17	27	374·6	58	1179	89	2242	120	3510
3 1/2	17·48	8 3/4	69·11	28	395·6	59	1210	90	2280		
3 5/8	18·42	9	72·09	29	417·0	60	1241	91	2318		
3 3/4	19·39	9 1/4	75·12	30	438·7	61	1272	92	2356		
3 7/8	20·37	9 1/2	78·18	31	460·8	62	1304	93	2395		
4	21·36	9 3/4	81·29	32	483·3	63	1335	94	2433		

TABLE XIV.—Of the Velocities in Feet per Second, due to given Heads.

Head in Inches	A. Coef. 1·0	B. Coef. ·96	C. Coef. ·86	D. Coef. ·635	Head in Inches	A. Coef. 1·0	B. Coef. ·96	C. Coef. ·86	D. Coef. ·635
1/64	·29	·2784	·2494	·18415	1	2·317	2·2224	1·9930	1·4713
1/32	·41	·3936	·3524	·2603	1¼	2·590	2·4864	2·2270	1·6446
1/16	·58	·5568	·4988	·3683	1½	2·837	2·7235	2·4398	1·8015
1/8	·82	·7872	·7052	·5207	1¾	3·065	2·9424	2·6360	1·9463
3/16	1·0	·9600	·8600	·6350	2	3·276	3·145	2·8174	2·0803
1/4	1·158	1·1117	·9959	·7353	2¼	3·475	3·336	2·9885	2·2066
5/16	1·295	1·2432	1·1140	·8223	2½	3·663	3·516	3·1502	2·3260
3/8	1·418	1·3613	1·2195	·9004	2¾	3·842	3·688	3·3041	2·4397
7/16	1·532	1·4707	1·3175	·9728	3	4·012	3·851	3·4503	2·5476
1/2	1·638	1·5725	1·4087	1·0401	3¼	4·176	4·009	3·5914	2·6517
9/16	1·737	1·6675	1·4938	1·1030	3½	4·334	4·161	3·7272	2·7521
5/8	1·831	1·7577	1·5747	1·1627	3¾	4·486	4·306	3·8580	2·8486
11/16	1·921	1·8442	1·652	1·2198	4	4·633	4·448	3·9844	2·9420
3/4	2·006	1·9258	1·725	1·2738	4½	4·914	4·717	4·2260	3·1204
13/16	2·088	2·0045	1·796	1·3259	5	5·180	4·973	4·455	3·2893
7/8	2·167	2·0803	1·863	1·376	6	5·675	5·448	4·881	3·6036
15/16	2·243	2·1533	1·929	1·424					

(49) If the discharging orifice is not a thin plate, the discharge will vary within certain limits from that given by our table. If, for instance, the crest were 2 or 3 inches thick, it might be expected that the discharge would be reduced by the extra friction, and for thin currents this would no doubt be the case; but, on the other hand, the effect of a thick lip is to diminish the vena-contracta, and thereby *increase* the discharge (3), and this will be more influential in deep overflows than in shallow ones. The experiments that have been made on this subject are so discordant among themselves, that we cannot make use of them satisfactorily. One set of experiments gives a coefficient of ·723 as a mean of thirty experiments on a weir 10 feet long and 2 inches thick; while another set of eleven experiments by the same authority, and with a weir precisely similar, gives a mean of ·557 only. Our Table XIII. is calculated with a coefficient of ·667.

(50) We have so far supposed that the head has been measured from still water, or that the channel was of very large area in proportion to the discharging orifices. Where the

channel is of small area the water will have a sensible velocity, and if this is considerable, it will increase the discharge, and correction must be made for it by adding to the measured head that due to the observed velocity of approach. Table XIV. gives the head due to a range of velocities, such as are likely to be met with in ordinary practice. Column A gives the theoretical velocity, which would never be attained except with orifices having the form of the vena-contracta, and measured at the smallest part. The other columns are calculated for the coefficients given by Eytelwein. B applies to very wide openings whose bottom is on a level with that of the reservoirs, to sluices with bottom and side walls in a line with the orifice, and to bridges with pointed piers. C applies to narrow openings whose bottom is on a level with that of the reservoirs, also to smaller sluices with side walls, and to abrupt projections generally, square piers of bridges, &c.; and D applies to openings in sluices without side walls, and with bottom not at same level. Thus, in our case of a weir with $3\frac{5}{8}$ inches overfall, if the velocity of approach had been 9 inches, or ·75 of a foot per second, we find that the head due to that velocity in column B$=\frac{1}{8}$ inch, and the head on the weir becomes $3\frac{3}{4}$, and the discharge $19{\cdot}39 \times 60 = 1163{\cdot}4$ gallons instead of 1105·2, as we found it for still water. But in making this correction the *mean* velocity should be taken, not the maximum central surface velocity (53).

(51) These rules for weirs apply also with approximate correctness to an overflow pipe to a tank, as per Fig. 26, which may be taken as a circular weir, and the discharge calculated by Table XIII., taking the circumference of the lip of the trumpet-mouth as the length of the weir. Or it may be calculated direct by the formulæ $D \times \sqrt{D} \times d \times 8{\cdot}4 = G$, and $\frac{G}{8.4 \times D \times \sqrt{D}} = d$, and $\sqrt[3]{\frac{G}{8{\cdot}4 \times d}} = \sqrt{D}$, in which d = the diameter of trumpet-mouth in inches, and D = depth of water over the lip (measured from still water) in inches, and G = gallons discharged per minute. Table XV. has been calculated by this rule. The size of the overflow pipe must be determined by the ordinary rules, or by Tables II. and III. It will be found that the discharge is governed principally by the head due to velocity. For tanks 3 feet deep, and with overflow pipe of the same length, Table XVI.

TABLE XV.—The Discharge of Overflow Pipes for Tanks, &c.

Depth of Overflow in inches.	DIAMETER OF THE TRUMPET-MOUTH IN INCHES.													
	2	3	4	5	6	7	8	9	10	11	12	14	16	18
	GALLONS DISCHARGED PER MINUTE.													
½	6	9	12	15	18	21	24	27	30	33	36	40	47	53
¾	11	16	22	27	32	38	43	48	54	59	65	75	86	97
1	17	25	34	42	50	59	67	75	84	92	100	118	134	151
1¼	23	35	47	57	70	82	94	106	117	129	140	164	188	211
1½	31	46	62	77	92	108	123	139	154	170	185	216	247	278
1¾	39	58	78	97	116	136	155	175	194	214	233	272	311	350
2	47	71	95	119	142	166	190	214	237	261	285	332	380	427
2¼	,,	85	113	142	170	198	227	255	283	312	340	397	453	510
2½	,,	100	133	166	199	232	265	299	332	365	398	465	531	597
2¾	,,	116	155	194	233	271	310	349	388	427	465	543	621	698
3	,,	131	174	218	262	305	349	392	436	480	523	611	698	785
3¼	,,	,,	197	246	295	344	394	443	492	541	590	689	787	886
3½	,,	,,	220	275	330	385	440	495	550	605	660	770	880	990
3¾	,,	,,	244	305	366	427	488	549	610	671	732	854	897	1098
4	,,	,,	,,	330	403	470	537	605	672	740	806	941	1075	1210

gives the maximum discharge. For greater lengths with vertical pipes it will be a little greater, but not very much, because the friction from the increased length of pipe absorbs the head in the same proportion. Say we had to provide for 400 gallons per minute, Table XVI. shows that 4 inches is the smallest size of pipe admissible, and allowing 2½ inches for overflow, Table XV. gives 12 inches for the diameter of trumpet-mouth. We must also make some allowance for contingencies, and in such a case the lip of the trumpet-mouth must not be less than 3 inches below the top of the tank, and 3 inches is practically lost in the useful depth of the tank.

TABLE XVI.—Of the Maximum Discharge of Vertical Pipes 3 Feet long.

Diameter of Pipe in Inches.	Maximum Discharge of Gallons per Minute.
1	19
1½	45
2	88
2½	145
3	220
3½	303
4	400
5	630
6	920
7	1300

(52) Fig. 27 shows a simple contrivance of the late Mr. Appold, by which this loss may be avoided, and the water level not allowed to rise more than about one-eighth of an inch above the top of the trumpet-mouth, even when the descending pipe is discharging full bore. B is a spherical or dished cover of sheet iron or copper, &c., supported on four brackets, C C, cast on the pipe, so that its lower lip, D, is at the same level as the lip of the trumpet-mouth. When the water rises to that level, it does not immediately flow over when the lip is dry, but rises perhaps one-tenth of an inch above it, and then suddenly overflows, and running down creates a partial vacuum under the cover, causing the water to rise there above the level of the water in the tank, filling

the pipe full bore. The air under the cover is swallowed up by the rush of water, and the maximum quantity which the pipe can carry is delivered; and this continues till the water, being drawn down below the lip of the cover D, air enters, and the action suddenly ceases, to be again repeated should the water rise. It is usual to construct these pipes so as to serve as a wash-out valve, the joint at the bottom being turned and bored so as to be a water-tight valve.

Table XVII.—For open Channels, Canals, and Rivers, giving the Mean Velocity throughout the Section, corresponding to observed Central Surface Velocities.

Surface Velocity.	Mean Velocity.	Surface Velocity.	Mean Velocity.	Surface Velocity.	Mean Velocity.	Surface Velocity.	Mean Velocity.
1	·84	26	21·84	51	42·84	76	63·84
2	1·68	27	22·68	52	43·68	77	64·68
3	2·52	28	23·52	53	44·52	78	65·52
4	3·36	29	24·36	54	45·36	79	66·36
5	4·2	30	25·2	55	46·20	80	67·2
6	5·04	31	26·06	56	47·04	81	68·04
7	5·88	32	26·88	57	47·88	82	68·88
8	6·72	33	27·72	58	48·72	83	69·72
9	7·56	34	28·56	59	49·56	84	70·56
10	8·4	35	29·4	60	50·4	85	71·40
11	9·24	36	30·24	61	51·24	86	72·24
12	10·08	37	31·08	62	52·12	87	73·08
13	10·92	38	31·92	63	52·92	88	73·92
14	11·76	39	32·76	64	53·76	89	74·76
15	12·60	40	33·6	65	54·6	90	75·6
16	13·44	41	34·44	66	55·44	91	76·44
17	14·28	42	35·28	67	56·28	92	77·28
18	15·12	43	36·12	68	57·12	93	78·12
19	15·96	44	36·96	69	57·96	94	78·96
20	16·8	45	37·8	70	58·8	95	79·80
21	17·64	46	38·64	71	59·68	96	80·64
22	18·48	47	39·48	72	60·48	97	81·48
23	19·32	48	40·32	73	61·32	98	82·32
24	20·16	49	41·16	74	62·16	99	83·16
25	21·0	50	42·0	75	63·00	100	84·00

Canals and Water-courses.—(53) When water flows in open channels we may find the discharge by observing the velocity of the current, and calculating with that and the known area of the section. But for this purpose we require the *mean velocity throughout the section*, which is not given by observation. The velocity varies, being a maximum in the centre, and at the surface in most cases, diminishing from thence to the banks at either side and to the bottom, where it is a minimum. The best experiments we have, give the mean velocity throughout the section at 83 per cent. of the maximum central surface velocity, which is usually the velocity observed, and is easily obtained by a float on the surface of the stream. Table XVII. gives the mean velocity by this rule. Thus if a channel, whose area is 24 square feet, has by observation a central surface velocity of 35 feet per minute, the mean velocity by table is 29·4 feet, and the discharge will be $29{\cdot}4 \times 24 = 705{\cdot}6$ cubic feet, or $705{\cdot}6 \times 6{\cdot}23 = 4396$ gallons.

(54) The quantity of water discharged by a river or any open channel may also be determined by calculation when we know the fall in a given distance, and have a cross section of the stream. There are many formulæ by which this may be done. Eytelwein's is $V = {\cdot}91\sqrt{F \times R}$, in which V = the mean velocity throughout the whole of the cross sectional area in inches per second; F = the fall in two miles in inches; and R = the hydraulic radius or hydraulic mean depth, also in inches.

(55) R is found by dividing the cross sectional area of the stream in square inches, by the border or wetted perimeter in inches. Thus, in Fig. 14, the area is $72 \times 30 = 2160$ square inches, and the wetted border being $72 + 30 + 30 = 132$ inches, the hydraulic radius is $\frac{2160}{132} = 16{\cdot}36$ inches. But for large areas, to which this rule is usually applied, it is more convenient to take the hydraulic radius in feet, which may be done by taking the measurements in feet. Thus, in the last example (Fig. 14), the area being 15 square feet and the border 11 feet, we have the hydraulic radius $\frac{15}{11} = 1{\cdot}363$ feet. Say we required the velocity of such a channel with a fall of 10 inches per mile (or 20 inches in 2 miles), then by Eytelwein's rule we have $\sqrt{20 \times 16{\cdot}36} \times {\cdot}91 = 16{\cdot}46$ inches per second, or 1·372 feet; and from this we get the discharge of the channel, whose area is 15 feet, at $1{\cdot}372 \times 60 \times 15 = 1234{\cdot}8$

cubic feet, or 7693 gallons per minute. To find the fall to give any required velocity, we have $\frac{\left(\frac{V}{\cdot 91}\right)^2}{R} = F$. Table XVIII. has been calculated by the formula $V = \cdot 91\sqrt{FR}$, and gives the velocity due to a given hydraulic radius and fall, or the fall necessary to produce any required velocity with a given hydraulic radius.

(56) Thus for the case, Fig. 14, the hydraulic radius is, as we have seen, 1·363 feet, which may be estimated from Table XVIII. to be 83 feet per minute, the velocity of discharge, and which we found by the rule to be 1·372 feet per second = 82·32 feet per minute.

Table XIX.—For the Discharge of Canals, Rivers, &c.

Mean Velocity in feet per Second.	R. S.	Mean Velocity in feet per Second.	R. S.
·025	·0000006734	·6	·00005466
·05	·000001489	·65	·00006284
·075	·00000244	·7	·00007158
·1	·000003538	·75	·00008197
·125	·000004771	·8	·00009183
·15	·000006155	·85	·00010113
·175	·000007656	·9	·0001121
·2	·000009307	·95	·0001236
·225	·0000111	1·0	·0001367
·25	·00001303	1·1	·00016146
·275	·00001510	1·2	·0001895
·3	·00001730	1·3	·00022096
·325	·00001966	1·4	·0002535
·35	·00002214	1·5	·00028703
·375	·00002477	1·6	·00032402
·4	·00002753	1·7	·0003644
·425	·000030753	1·8	·0004047
·45	·000033484	1·9	·000453
·475	·00003666	2·0	·0004943
·5	·00004000	2·5	·000757
·55	·00004705	3·0	001083

(57) Again, say we require to determine the fall necessary in the same channel 100 yards long to discharge 3000 cubic

feet per minute. The area of the channel being 15 square feet, the velocity of discharge must obviously be $\frac{3000}{15}=200$ feet per minute. Then, the hydraulic mean radius being 1·363, we have to look in the table between the nearest numbers in the table (1·3 and 1·4) for the 200, the required velocity, which we find to be given by 5 feet per mile, or ·0341 inches per yard, and for our case ·0341 × 100 = 3·41 inches fall.

(58) Take another case shown by Fig. 15 of an open cutting with sloping bank, and say that we have to determine the discharge with a fall of 8 inches per mile. First we have the area $\frac{30+20}{2} \times 2{\cdot}5 = 62{\cdot}5$ square feet, and the wetted perimeter being $5{\cdot}6+20+5{\cdot}6 = 31{\cdot}2$, we get the hydraulic radius $\frac{62{\cdot}5}{31{\cdot}2}=2$ feet, which, per Table XVIII., with a fall of 8 inches per mile, will have a velocity of 89·2 feet per minute, and a discharge of 89·2 × 62·5 = 5575 cubic feet, or 34732 gallons per minute.

TABLE XX.—Of the Calculated Velocities of Discharge by Channel, Fig. 15.

Fall in Inches per Mile.	R.	S.	R. S.	Mean Velocity by Table XIX.		Velocity by Table XVIII.	Error of Table XVIII.
				Feet per Second.	Feet per Min.	Feet per Min.	Per Cent.
1	2	·0000158	0000316	.4375	26·25	31·7	20·7
2	2	·0000316	0000632	·65	39·0	44·6	14·3
3	2	·0000474	0000948	·82	49·2	55·0	11·8
4	2	·0000632	·0001264	·96	57·6	62·4	8·3
6	2	·0000948	·0001896	1·2	72·0	77·8	8·05
8	2	·0001264	·0002528	1·38	82·8	89·2	7·7
10	2	·0001580	·0003160	1·56	93·6	100·4	7·3
12	2	-0001896	·0003792	1·75	105·0	111·0	6·0
24	2	·0003792	·0007584	2·5	150·0	156·0	4·0

(59) Table XVIII. gives a ready solution of ordinary cases, but for very low velocities there is a considerable error. Prony, Saint Venant, and Eytelwein, have given rules which give more correct results for such cases. From

a comparison of these three rules, with ninety-six experiments on the discharge of canals and rivers by several experimenters, we find that Eytelwein's rule agrees best with thirty-eight experiments, Saint Venant with thirty-two, and Prony with twenty-six. Eytelwein's formula may take the following form:—$\frac{(V+\cdot1089)^2-0118858}{8975}=R\ S$, in which V = the velocity in feet per second, R = the hydraulic radius in feet or $\frac{area}{border}$, and S = the slope, or $\frac{H}{L}$. Table XIX. has been calculated by this rule. Say we have to determine the mean velocity in the channel shown by Fig. 15 with a fall of only 1 inch per mile. The value of R we found before (58) to be 2, and S for our present case is $\frac{1}{1760\times36}=\cdot0000158$. Therefore R S = ·0000316, which by Table XIX. is found intermediate between the velocities ·425 and 45, say ·4375 feet per second, or 26·25 feet per minute, instead of 31·7 feet, as in Table XVIII. But for a fall of 12 inches per mile, the difference is only about 6 per cent. Table XX., which gives the calculated velocities with different falls by Tables XVIII. and XIX. with the channel, Fig. 15, will enable the engineer to determine which table to use in any particular case. The Table XVIII. is correct enough for practice in most cases, with falls over 8 inches per mile.

(60) It must not be overlooked that these rules, tables, and calculations, give the head due to friction only, and do not include the head due to velocity. Thus in (57) we had a *mean* velocity of 200 feet per minute, or 3·33 feet per second, which by Table XVII. is equal to 4 feet maximum surface velocity, and to obtain that velocity, irrespective of friction, we shall require by Table XIV. (column B) a head of 3¼ inches; the total head is therefore 3·41 + 3·25 = 6·66 inches, and in this case the head for velocity is nearly equal to that due to friction. Again in (58), we found a *mean* velocity of 89·2 feet per minute, or say 1·5 feet per second, which is equal to 1·8 maximum surface velocity, and to ⅝ inch head only, so that if the channel were two miles long, with 16 inches fall, the loss of ⅝ inch would have no sensible effect on the discharge, but if the channel were ⅛th of a mile long, the head allowed for it would only be 1 inch, and the loss of ⅝ inch would have

a serious effect. With very short channels, whose discharge is sought, the best course is to assume a fall somewhat less than the fall given, and calculate as in (57), adding the head for velocity as above, and by trial and error, approximate to the true discharge. Thus in the case (58), say the channel were $\frac{1}{8}$th of a mile long; instead of 8 inches, let us assume a fall of say 5 inches per mile, then, with the known hydraulic radius 2, we have by Table XVIII., a *mean* velocity of 71 feet per minute, or 1·2 feet per second. or by Table XVII., 1·4 feet maximum, which by Table XIV. $= \frac{3}{8}$ inch head. The fall of 5 inches per mile is equal to $\frac{5}{8}$ inch for $\frac{1}{8}$th of a mile, and the head for velocity being $\frac{3}{8}$ we have a total of $\frac{5}{8} + \frac{3}{8} = 1$ inch, or 8 inches per mile, the given head. The velocity of discharge with a channel $\frac{1}{8}$th of a mile long, Fig. 15, is therefore 71 feet per second, instead of 89·2 feet as for a very long channel, say 2 or 3 miles long.

(61) *Openings in Bridges, &c.*—The head lost by a stream in passing through bridges is almost wholly that due to velocity alone, the length of the contracted channel being in most cases so short, as to have little influence on the discharge. The head may be estimated by Table XIV.; say we take the case (58) of a stream, Fig. 15, discharging 5575 cubic feet per minute, and passing through a bridge 8 feet wide, and 3 feet deep. The area being $3 \times 8 = 24$ feet, the velocity must be $\frac{5575}{24 \times 60} = 3{\cdot}87$ feet per second, which, with pointed piers, would require by Table XIV., column B, 3 inches head; but we have seen (60), that the stream approaches with a velocity due to $\frac{5}{8}$ inch head, the head at the bridge is therefore $3 - \frac{5}{8} = 2\frac{3}{8}$ inches. With square headed piers (column C), we have 4 inches head, or at the bridge, $4 - \frac{5}{8} = 3\frac{3}{8}$ inches head.

(62) *Submerged Openings.*—The discharge by a submerged orifice, may be calculated by Table XIV.; thus an opening 2 feet × 3 feet, or 6 square feet area, in a sluice gate, .&c., with a difference of 5 inches water level on its two sides, would discharge (column D) $6 \times 3{\cdot}2893 = 19{\cdot}7$ cubic feet per second. With 4 feet head, by Tables X. or XI., the theoretical velocity is 16 feet per second, and the discharge would be $6 \times 16 \times {\cdot}635 = 60{\cdot}96$ cubic feet per second.

NOTE TO TABLES III. & V.

Rusted Pipes.—The tables and rules for pipes, are adapted only to clean and even surfaces; but some waters, especially those from the granite formation, contain a great deal of oxygen, which rapidly decomposes iron, forming rust, which is deposited, not in an even surface, but in nodules or carbuncles. These retard the flow, not so much by the reduction of diameter, as by the alteration of the character of the surface. A notable case of this kind occurred at Torquay, where a pipe 14 miles long, composed of 14,267 yards of 10-inch, 10,085 yards of 9-inch, and 170 yards of 8-inch pipe, delivered only 317·4 gallons with 465 feet head. We may calculate the discharge as in (15), assuming 100 gallons, we have by Table III.

10 inch, ·00041115 × 14267 = 5·869 feet.
9 „ ·000697 × 10085 = 7·029 „
8 „ ·001256 × 170 = ·213 „

13·111 feet head,

and the discharge with the real head is $\frac{\sqrt{465} \times 100}{\sqrt{13{\cdot}111}}$ or $\frac{21{\cdot}564 \times 100}{3{\cdot}621}$ =595 gallons. The experimental discharge was therefore only 53 per cent. of the calculated, or in round numbers, the discharge was that due to ¼th of the head, so that ¾ths of the head was lost in undue friction. An ingenious scraper suggested by the late Mr. Appold, and worked by the pressure of the water, was passed through these pipes, and subsequently an improved one, by W. Froude, Esq., was used, with remarkably good results, the discharge being increased to 564 gallons, or within 5 per cent. of the calculated quantity. Dr. Angus Smith's process, by which pipes are coated all over with a black enamel, seems to be an effective remedy; such pipes have been used with Torquay water for years, without the slightest effect. The process is very cheap, being only about 5*s*. per ton for medium pipes; it can be effectually done only in the process of casting, while the pipes are new and hot. With such a smooth surface, the discharging power must be increased in a much higher ratio than the cost, so that such pipes must really be more economical than any other, and they should be used in *all* cases.

TABLE III.—Of the Head of Water necessary to force given Quantities of Water through Pipes 1 Yard Long.

Gall. per Min.	DIAMETER OF THE PIPE IN INCHES.						
	1	1½	2	2½	3	3½	4
	HEAD OF WATER IN FEET.						
1	·004115	·0005419	·0001286	·00004214	·00001694	·000007837	·000004019
2	·01646	·0021676	·0005144	·00016855	·00006776	·00003134	·000016076
3	·037035	·0048771	·0011584	·00037925	·00015245	·000070515	·000036171
4	·06584	·0086704	·0020576	·00067424	·00027104	·00012536	·000064304
5	·102875	·0135475	·003215	·0010535	·0004235	·000195875	·000100475
6	·14814	·0195084	·0046336	·00151704	·00060984	·00028206	·000144684
7	·201635	·0265531	·0063014	·00206486	·00083006	·000383915	·000196931
8	·26336	·0346816	·0082304	·00269696	·00108416	·00050144	·000257216
9	·333315	·043894	·0104166	·00341334	·00137214	·000634635	·000325539
10	·4155	·05419	·01286	·004214	·001694	·0007838	·0004019
20	1·646	·21676	·05144	·016855	·006776	·003134	·0016076
30	3·7035	·48771	·11584	·037925	·015245	·007075	·0036171
40	6·584	·86704	·20576	·067424	·027104	·012536	·0064304
50	10·2875	1·35475	·3215	·10535	·04235	·0195875	·0100475
60	14·814	1·95084	·46336	·151704	·060984	·028206	·0144686
70	20·1635	2·65531	·63014	·206486	·083006	·0383915	·0196931
80	26·336	3·46816	·82304	·269696	·108416	·050144	·0257216
90	33·3315	4·3894	1·04166	·341334	·137214	·0634635	·0325539
	DIAMETER OF THE PIPE IN INCHES.						
	5	6	7	8	9	10	12
	HEAD OF WATER IN FEET.						
10	·0001317	·00005292	·00002449	·00001256	·00000697	·00000411152	·0000016538
20	·0005268	·00021168	·00009796	·00005024	·00002788	·0000164608	·0000066152
30	·0011853	·00047628	·00022041	·00011304	·00006273	·0000370368	·0000148842
40	·002003157	·00080491	·000372493	·0001910376	·0001060137	·00006259219	·0000251543
50	·0032925	·0013230	·00061225	·0003140	·00017425	·00010288	·000041345
60	·0047412	·00190512	·00088164	·00045216	·00025692	·0001481472	·0000595368
70	·0064533	·00259308	·00120001	·00061544	·00034153	·0002016448	·0000810762
80	·0084288	·00338688	·00156736	·00080384	·00044608	·0002633728	·0001058432
90	·0106677	·00428652	·00198369	·00101736	·00056457	·0003333312	·0001339578

NOTE.—For intermediate numbers, see body of general Table III., as explained in (10) page 6.

HYDRAULIC TABLE III.—Diameter of the Pipe in Inches.

Gall. per Minute.	1	1½	2	2½	3	3½	4	5	6	7	8	9
100	41·15	5·419	1·286	·4214	·1694	·07838	·04019	·01317	·005292	·002449	·001256	·000697
110	49·79	6·557	1·556	·5099	·20497	·094804	·04863	·015396	006403	·0029633	·00151976	·00084337
120	59·256	7·8034	1·8518	·60681	·24394	·112824	·057874	·0189648	·0076205	·0035266	·0018086	·00100368
130	69·543	9·1581	2·1733	·71216	·28628	·1324115	·067921	·0222573	0089435	·00413881	·00212264	·00117793
140	80·654	10·621	2·5206	·82594	·33202	·153566	·078772	·0258132	·0103723	·00480004	·00246176	·00136612
150	92·59	12·193	2·8935	·94815	·38115	·1762875	·0904275	·0296325	·011907	·00551025	·0028260	·00156825
160	105·344	13·872	3·2922	1·07878	·43366	·2005760	·1028864	·0337152	·0135475	·00626944	·00321536	·00178432
170	118·924	15·6609	3·71854	1·2178	·48596	·226431	·116149	·0380613	·0152939	·0070776	·00362984	·00201433
180	133·326	17·5576	4·1666	1·36533	·54906	·253854	·1312156	·042671	·0171461	·00793476	·00406944	·00225828
190	148·55	19·5626	4·6425	1·52125	·61173	·282843	·145086	·0475437	·0191041	·00884089	·00453416	·00251617
200	164·60	21·676	5·144	1·6856	·67760	·313400	·16076	·05268	·021168	·009796	·0050240	·00278800
210	181·47	23·897	5·6713	1·8584	·74705	·345523	·177238	·0580797	·0233377	·01080009	·00553896	·00307377
220	199·166	26·228	6·224	2·0396	·819896	·379214	·19452	·063743	·0256133	·01185316	·006079	·00337348
230	217·68	28·666	6·8029	2·2292	·89613	·414471	·212605	·069669	·027995	·01295521	·0066442	·00368713
240	237·024	31·2135	7·4074	2·42726	·97574	·451296	·231494	·075859	·030482	·01410624	·00723456	·00401472
250	257·19	33·869	8·0375	2·63375	1·05875	·489687	·251187	·0823125	·033075	·0153062	·0078500	·00435625
260	278·174	36·6320	8·6933	2·8487	1·14514	·529646	·271684	·0890292	·0357739	·01655524	·00849056	·00471172
270	299·98	39·504	9·37494	3·0710	1·23493	·571172	·292985	·0960093	·0385787	·01785321	·00915624	·00508113
280	322·616	42·484	10·0822	3·30378	1·3281	·614264	·315089	·1032528	·0414893	·01920016	·00984704	·00546448
290	346·07	45·574	10·8153	3·5440	1·4246	·6589235	·337998	·1107597	·044506	·02059609	·01056296	·00586177
300	370·35	48·771	11·584	3·7926	1·5246	·705150	·36171	·11853	·047628	·0220410	·0113040	·0062730
310	395·45	52·076	12·358	4·0496	1·6279	·752944	·316226	·126554	·050856	·0235349	·01207016	·00699817
320	421·376	55·500	13·1686	4·3151	1·73465	·802304	·411546	·134861	·054190	·02507776	·0128614	·00713728
330	448·124	59·013	14·004	4·5890	1·84476	·8532315	·437669	·143421	·057630	·0266961	·01367784	·00759033
340	475·694	62·644	14·874	4·8714	1·9583	·905726	·464596	·152245	·0611755	·02831044	·01451936	·00805732
350	504·09	66·383	15·753	5·16215	2·0752	·959787	·492327	161333	·064827	·03000025	·01538600	·00853825
360	533·304	70·23	16·666	5·46134	2·19622	1·015416	·52486	·170683	·068584	·03173904	·01627776	·00903312
370	563·34	74·186	17·605	5·7690	2·3362	1·072611	·55020	·180297	·072447	·03352681	·01719464	·00954193
380	594·206	78·250	18·570	6·0850	2·4469	1·131374	·580344	·1901748	·0764165	·03536356	·01813664	·01006468
390	625·89	82·423	19·560	6·4095	2·5766	1·191704	·61129	·2003157	·080491	·0372493	·01910376	·01060137
400	658·40	86·704	20·576	6·7424	2·7104	1·25360	·64304	·210720	·084672	·0391840	·02009600	·0111520
410	691·73	91·093	21·618	7·0837	2·8476	1·317074	·675594	·2213877	·0889585	·04116769	·02111606	·01171658
420	725·880	95·591	22·685	7·4335	2·9882	1·382094	·708950	·2323188	·0933509	·04320036	·02215584	·01229508

HYDRAULIC TABLE III.—Diameter of the Pipe in Inches—*continued.*

Gall. per Minute.	1	1½	2	2½	3	3½	4	5	6	7	8	9
430	760·86	100·197	23·897	7·7917	3·1322	1·44869	·743113	·243513	·097849	·04528181	·02322344	·01288753
440	796·664	104·912	24·897	8·1584	3·27958	1·516856	·77808	·25497	·1024531	·0474126	·0243162	·01349392
450	833·287	109·735	26·041	8·5333	3·4304	1·586587	·813847	·266693	·107163	·0495922	·0254340	·01411425
460	870·734	114·666	27·212	8·9168	3·5845	1·657886	·85042	·278677	·1119789	·0518208	·0265769	·01474852
470	909·00	119·706	28·408	9·3087	3·7420	1·730752	·887797	·290925	·1169003	·0540984	·02774504	·01539678
480	948·096	124·854	29·630	9·70906	3·90298	1·805184	·925978	·303437	·1219277	·05642496	·02893824	·01605888
490	988·01	130·11	30·877	10·1178	4·0673	1·881184	·964962	·3162117	·127061	·0588005	·03015656	·01673497
500	1028·75	135·475	32·15	10·535	4·235	1·95875	1·00475	·32925	·13230	·061225	·031400	·0174250
520	1112·70	146·53	34·7734	11·39465	4·5806	2·118584	1·08674	·3561168	·1430957	·06622096	·03396224	·01884688
540	1200·00	158·018	37·500	12·284	4·9397	2·284686	1·17194	·384037	·154315	·07141284	·03662496	·02032452
560	1290·46	169·938	40·329	13·2151	5·31238	2·457056	1·26036	·413011	·165957	·07680064	·03938816	·02185792
580	1384·286	182·295	43·261	14·1759	5·6986	2·63569	1·351992	·44304	·1780229	·0823844	·04225184	·02344708
600	1481·40	195·084	46·336	15·1704	6·0984	2·82060	1·44684	·47412	·190512	·0881640	·045216	·0250920
620	1581·80	208·306	49·434	16·1986	6·51174	3·011774	1·54490	·506215	·203425	·09413956	·0482806	·02679268
640	1685·5	222·00	52·670	17·2605	6·9386	3·209216	1·64618	·539443	·216760	·1031104	·05144576	·0285491
660	1792·5	236·05	56·018	18·356	7·37906	3·412926	1·750676	·573685	·2305195	·10667844	·05471136	03086132
680	1902·78	250·57	59·497	19·4855	7·83306	3·62290	1·85838	·608981	·244702	·11324176	·05807744	·03222928
700	2016·35	265·531	63·014	20·6486	8·3006	3·839150	1·96931	·64533	·259308	·1200010	·0615440	·0341530
720	2133·22	280·92	66·666	21·8454	8·7849	4·06166	2·09945	·682733	·2743373	·1269562	·06511104	·03613248
740	2253·374	296·744	70·421	23·076	9·449	4·29045	2·2008	·721189	·289790	·13410724	·06877856	·03816772
760	2376·82	313·000	74·280	24·340	9·78774	4·52549	2·321374	·760699	·305666	·1414542	·07254656	·04025872
780	2503·56	329·692	78·240	25·638	10·3063	4·766814	2·44516	·801263	·321965	·1489972	·07641504	·04240548
800	2633·6	346·816	82·304	26·9696	10·8416	5·0144	2·57216	·84288	·338688	·1567360	.0803840	·044608
820	2766·93	364·373	86·471	28·335	11·3905	5·26825	2·70237	·885551	·355834	·1646707	.08446424	·0468663
840	2903·52	382·364	90·74	29·734	11·95286	5·528376	2·83580	·929275	·373403	·17280144	.08862336	·0491803
860	3043·45	400·79	95·59	31·1667	12·5288	5·794766	2·97245	·974052	·391396	·1811272	.09289376	·05155012
880	3186·66	419·647	99·588	32·6335	13·11834	6·067424	3·11231	1·02988	·409812	·1896506	.0972646	·05397568
900	3333·15	438·94	104·166	34·1334	13·7214	6·34635	3·25539	1·06677	·428652	·198369	.1017360	·0564570
920	3482·9	458·664	108·847	35·667	14·388	6·631544	3 40168	1·114709	·447915	·2072834	.1063078	·0589941
940	3636·0	478·823	113·630	37·235	14·968	6·92300	3·55119	1·16370	·467601	·2163936	.11098016	·06158692
960	3792·4	499·417	118·518	38·836	15·6119	7·220736	3·70391	1·213747	·487711	·2256998	.11575296	·06423552
980	3952·0	520·44	123·51	40·471	16·2692	7·52473	3·85985	1·26485	·508244	·285202	·12062624	·0669899
1000	4115·0	541·90	128·60	42·14	16·940	7·8350	4·0190	1·3170	·52920	·244900	·125600	·069700

HYDRAULIC TABLE III.—Diameter of the Pipe in Inches—*continued.*

Gall. per Minute.	10	12	14	15	16	18	20	21	24
100	·000411152	·00016538	·000076516	·000054192	·000039246	·00002178	·00001286	·000010076	·0000051682
110	·000497939	·00020011	·0000925844	·000065572	·0000474876	·000263538	·0000155606	·00001219196	·0000062535
120	·000592589	·000238147	·0001101830	·0000780365	·000056514	·000031363	·0000185184	·0000145094	·0000074432
130	·000695469	000279492	·000129312	·0000915845	·0000663267	·000036808	·0000217334	·0000170284	·0000087343
140	·000806579	·0000324145	·0001499714	·000106216	·0000769222	·000042689	·0000252056	·000019749	·0000101297
150	·000925920	·000372105	·000172161	·000121932	·0000883035	·000049005	·000028935	·0000226710	·0000116285
160	·0010534912	·0004233728	·000195881	·000138732	·0001004697	·0000557568	·0000329216	·0000257945	·0000132306
170	·0011892928	.000477948	·0002211312	·000156615	·0001134209	·000062944	·0000371654	·0000291196	·000014936
180	·0013333248	·0005358312	·0002479118	·000175582	·0001270570	·0000705672	·0000416664	·000032646	·000016745
190	·001485587	·0005970218	·000276223	·000195633	·000141678	·0000786258	·0000464246	·000036374	·000018657
200	·00164608	·00066152	·000306064	·000216768	·000156984	·00008712	·00005144	·000040304	·0000206728
210	·001814803	·0007293258	·0003374356	·000238987	·0001730749	·0000960498	·0000567126	·000044435	·0000227918
220	·00199175	·000800439	·000370337	·00026229	·00018995	·000105415	·000062242	·000048768	·000025014
230	·00217694	·00087486	·000404769	·000286676	·000207611	·000115218	·000068029	·000053302	·0000273398
240	·002370355	·000952589	·000440732	·000312146	·00022606	·000125453	·000074074	·0000580378	·000029773
250	·0025720	·001033625	·00478225	·00033870	·000245287	·000136125	·000080375	·000062975	·0000323112
260	·002781875	·001117969	·000517248	·000366238	·00026531	·000147233	·000086934	·0000681138	·000034937
270	·0030000	·00120562	·000557802	·00039506	·000286103	·000158776	·000093749	·000073454	·0000376762
280	·00322632	·001296579	·000599885	·000424865	·000307689	·000170755	·000100882	·0000789958	·000040519
290	·00346088	·001390846	·00064350	·000455755	·000330059	·00018317	·000108153	·000084739	·000043465
300	·00370368	·00148842	·00068864	·000487728	·000353214	·00019602	·00011574	·000090684	·000046514
310	·00395471	·00158930	·000735319	·000520785	·000377154	·000209306	·000123585	·000096830	·000049666
320	·004213965	·001693491	·0007832524	·000554926	·000401879	·000223027	·000131686	·0000103178	·000052922
330	·00448145	·001800988	·00083326	·000590151	·000427389	·000237184	·000140045	·000109728	·000056282
340	·00475717	·001911793	·00088452	·00062646	·000453684	·000251777	·000148662	·000116479	·000059744
350	·00504112	·0020269	·000937321	·000663852	·000480763	·000267805	·000157535	·000123431	·000063310
360	·005333299	·00214232	·000991647	·000702328	·000508228	·000282269	·000166666	·000130585	·0000669798
370	·005633709	·00226405	·00010475	·000741888	·000537278	·000298168	·000176053	·00013794	·000070753
380	·00594235	·002388087	·001104891	·000782532	·000566712	·000314503	·000185698	·000145497	·000074629
390	·006259219	·00251543	·001163808	·00082426	·000596693	·000331274	·00019560	·000153256	·000078608
400	·0065843	·00264608	·001224256	·000867072	·000627936	·00034848	·00020576	·000161216	·0000826912
410	·00691765	·002780038	·001286234	·000910967	·0000659725	·000366122	·000217077	·000169377	·000086877
420	·0072592	·002917303	·001349742	·000955947	·00069230	·000384199	·00022685	·000177741	·000091167

HYDRAULIC TABLE III.—Diameter of the Pipe in Inches—*continued*.

Gall. per Minute.	10	12	14	15	16	18	20	21	24
430	·0076090	·00305787	·001414781	·00100201	·000725658	·000402712	·000237781	·000186310	·000095560
440	·007967027	·003201757	·00148135	·001049157	·000759703	·000421661	·00024897	·000195071	·000100056
450	·00833328	·00334895	·00154945	·00109739	·000794732	·000441045	·000260415	·000204089	·000104656
460	·00870776	·00349944	·001619078	·001146703	·000830445	·000460873	·000272118	·000213208	·000109359
470	·00909048	·00365324	·001690288	·001197101	·000866944	·00048112	·000284077	·000222579	·0001141655
480	·00948142	·00381035	·001762929	·00124858	·00090423	·000501811	·000296194	·000232151	·000119091
490	·009880595	·00397077	·001837149	·00130115	·00094229	·000522938	·00030877	·00024198	·000124554
500	·01028800	·0041345	·00191290	·0013548	·00098115	·0005445	·00032150	·00025190	·000129245
520	·01112750	·004471875	·0020690	·00146495	·001061228	·000588931	·000347735	·00027246	·000139748
540	·0120000	·00482248	·00223121	·001580239	·00114440	·000635105	·000374998	·000293816	·000150705
560	·012905267	·00518632	·00239954	·00169946	·001230754	·000683021	·00040329	·000315983	·000162075
580	·01384353	·00556338	·0025740	·001823019	·00132024	·00073268	·00043261	·000338957	·00017386
600	·01481472	·00595368	·00275457	·001950912	·00141286	·00078408	·00046296	·000362736	·000186055
620	·015818820	·00635721	·00294128	·00208314	·00150862	·000837231	·00049434	·00038732	·000198666
640	·01685586	·00677396	·00313409	·002219704	·001607516	·000892109	·00052675	·000412713	·00021169
660	·01792581	·007203953	·00333304	·002360604	·001709556	·00094874	·000560182	·00043891	·000225127
680	·019028685	·00764717	·003538100	·002505838	·001814735	·001007109	·000594666	·000465914	·00023898
700	·02016448	·00810762	·00374928	·00265541	·00192305	·00107122	·00063014	·000493724	·00025324
720	·0213331968	·00856930	·003966589	·002809313	·00203291	·001129075	·000666662	·00052334	·00026792
740	·02253484	·00905621	·004190016	·002967554	·00215111	·001192673	·000704213	·00055176	·00028301
760	·0237694	·00955235	·004419564	·00313013	·002266849	·001258013	·000742794	·000581990	·000298515
780	·02503687	·01006172	·00465523	·00329704	·00238773	·001325095	·0007824	·000613024	·00031443
800	·02633728	·01058432	·00489702	·003468288	·002511744	·00139392	·00082304	·00064486	·000330765
820	·0276706	·011120151	·005144936	·00364387	·00263890	·00146449	·000868306	·00067751	·00034751
840	·02903685	·011669213	·005398967	·003823787	·00276919	·001536797	·00090740	·000710962	·000364668
860	·0304360	·01223150	·00565912	·00400804	·00290263	·001610849	·000951126	·00074520	·00038224
880	·03186811	·01280703	·0059254	·004196628	·00303881	·001686643	·00099588	·000780285	·000400225
900	·03333312	·01339578	·006197796	·00438955	·00317893	·00176418	·00104166	·000816156	·000418624
920	·03483105	·01399888	·00647631	·00458681	·003321781	·00184349	·00108847	·000852832	·00043744
940	·03636191	·01461297	·00676095	·00478840	·00346778	·00192448	·00113631	·000890235	·00045666
960	·03792568	·0152414	·007051715	·00499433	·003616911	·00200724	·00118478	·000928604	·000476365
980	·03952238	·01588309	·007348597	·0052046	·00376920	·00209175	·001235074	·00096770	·00049821
1000	·0411520	·0165380	·00765160	·0054192	·00392460	·0021780	·0012860	·00100760	·00051682

HYDRAULIC TABLE III.

Gallons per Minute.	Diameter of the Pipe in Inches.						
	5	6	7	8	9	10	12
	Head of Water in Feet.						
2,000	5·268	2·1168	·9796	·5024	·2788	·164608	·066152
3,000	11·853	4·7628	2·2041	1·1304	·6273	·370368	·148842
4,000	21·072	8·4672	3·9184	2·0096	1·1152	·65842	·264608
5,000	32·925	13·239	6·1225	3·1400	1·7425	1·0288	·41345
6,000	47·412	19·0512	8·8164	4·5216	2·5092	1·481472	·595368
7,000	64·533	25·9308	12·0001	6·1544	3·4158	2·016448	·810762
8,000	84·288	33·8688	15·6736	8·0384	4·4608	2·633728	1·058432
9,000	106·677	42·8652	19·8369	10·1736	5·6457	3·333312	1·339578
10,000	131·70	52·920	24·490	12·560	6·9700	4·1152	1·65380
20,000	526·80	211·68	97·96	50·240	27·880	16·4608	6·6152

Gallons per Minute.	Diameter of the Pipe in Inches.						
	14	15	16	18	20	21	24
	Head of Water in Feet.						
2,000	·0306064	·0216768	·0156984	·008712	·005144	·0040304	·00206728
3,000	·068864	·0487728	·0353214	·019602	·011574	·0090684	·0046514
4,000	·1224256	·0867072	·0627936	·034848	·020576	·0161216	·00826912
5,000	·19129	·13548	·098115	·05445	·032150	·025190	·0129245
6,000	·275457	·1950912	·141286	·078408	·046296	·0362736	·0186055
7,000	·374928	·265541	·192305	·107122	·063015	·0493724	·025324
8,000	·489702	·3468288	·2511744	·139392	·082304	·064486	·0330765
9,000	·6197796	·438955	·317893	·176418	·104166	·0816156	·0418624
10,000	·765150	·54192	·392460	·217800	·128600	·100760	·0516820
20,000	3·06064	2·16768	1·56984	·87120	·5144	·40304	·206728
30,000	6·8864	4·87728	3·53214	1·9602	1·1574	·90684	·46514
40,000	12·24256	8·67072	6·27936	3·4848	2·0576	1·61216	·826912
50,000	19·129	13·548	9·8115	5·445	3·2150	2·5190	1·29245
60,000	27·5457	19·50912	14·1286	7·8408	4·6296	3·62736	1·86055
70,000	37·4928	26·5541	19·2305	10·7122	6·3014	4·93724	2·5324
80,000	48·9702	34·68288	25·11744	13·9392	8·2304	6·4486	3·30765
90,000	61·97796	43·8955	31·7893	17·6418	10·4166	8·16156	4·18624
100,000	76·515	54·192	39·246	21·780	12·8600	10·0760	5·16820

APPENDIX.

On the Strength of Water-Pipes.

(1) Barlow's rule for the strength of pipes to resist an internal pressure is $\frac{R \times P}{S - P} = T$, in which S = the cohesive strength of the metal, which for cast iron may be taken at 7·142 tons, or 16,000 pounds per square inch; P = the internal pressure per square inch, in the same terms as S—that is to say, if S be in tons, P will be in tons also, &c.; R = the radius of the inside of the pipe in inches; and T = the thickness of metal in inches; also $\frac{S \times T}{R + T} = P$, and $\frac{(R + T) \times P}{T} = S$.

These rules are based on the fact, that when a pipe is subjected to internal pressure, the whole section of the metal is not strained to the same extent, but that the strain is greatest near the centre, and diminishes with the distance therefrom. To illustrate this fact, take a pipe 10 inches diameter inside, and 20 inches outside, as per Fig. 1, and let an internal pressure be exerted until the inside diameter is extended from 10 inches to $10\frac{1}{8}$ inches, as in Fig. 2.

Fig. 1.

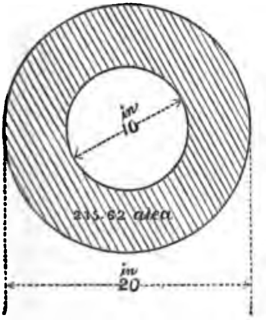
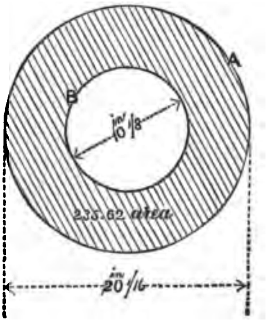


Fig. 2.



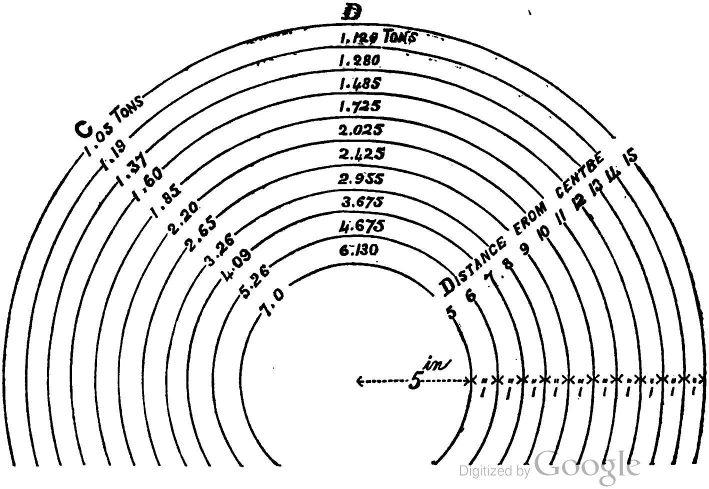
Now, if the metal at A were strained in the same proportion as at B, it would also be extended or stretched in the same proportion, and 20 inches would become $20\frac{1}{4}$ inches. But obviously the sectional *area* must be the same in all cases, and the area of 10 inches being 78·54, and of 20 inches = 314·16, we have $314·16 - 78·54 = 235·62$ for the area of the metal in Fig. 1; and the outside diameter in Fig. 2 must be found by adding the area of $10\frac{1}{8}$ inches (or 80·517) to 235·62, and we have $80·517 + 235·62 = 316·1357$, the area due to which is $20\frac{1}{16}$, the diameter at A, instead of $20\frac{1}{4}$, as it should have been if the metal had been strained to the same extent as at B. It will be seen from this that the extension varies as the square of the distance from the centre, for $\frac{\frac{1}{4} \times 5^2}{10^2} = \frac{1}{16}$, as we have found it.

(2) The extension of cast iron is not exactly proportional to the strain; the relations are given by the formulæ $W = \sqrt{\left(\frac{E}{·0000103 \times L} + 64·16\right)} - 8·01$, and $E = (000165 \times W) + (0000103 \times W^2) \times L$, in which

W = the strain on a bar, in tons per square inch;
L = the length of the bar in inches;
E = the extension in inches.

Applying this to the case of a thick pipe, as in Fig. 3, we

Fig. 8.



will assume the cohesive strength of cast iron at 7 tons per square inch, breaking weight. This is the strain on the inside filament of metal at the moment of rupture, and the extension for a length of 1 (which, as we want only proportional numbers, will answer our purpose) will be $(\cdot000165 \times 7)+(\cdot0000103 \times 7^2) = \cdot0016597$. Then the extension, 6 inches from the centre, will be $\frac{\cdot0016597 \times 5^2}{6^2} = \cdot00115257$, and the strain due to that by formula is equal to $\sqrt{\left(\frac{\cdot00115257}{\cdot0000103} + 64\cdot16\right)} - 8\cdot01 = 5\cdot26$ tons per square inch, and thus has been calculated column C in Fig. 3. Then the *mean* strain upon each ring is evidently the average of the strain at its internal and external periphery. Thus the mean strain on the first ring is $\frac{7+5\cdot26}{2} = 6\cdot13$ tons, and column D in Fig. 3 has been thus obtained.

(3) The bursting pressure of a 10-inch pipe, 1 inch thick, will therefore be $\frac{6\cdot13 \times 2}{10} = 1\cdot226$ tons per square inch; for 2 inches thick the mean strain is $\frac{6\cdot13+4\cdot675}{2} = 5\cdot4025$, and the bursting pressure $\frac{5\cdot4025 \times 4}{10} = 2\cdot61$ tons per square inch. Table I. gives the strength of a 10-inch pipe calculated on these principles. It will be observed, that in every case rupture takes place first at the inside filament of metal, the rest following instantaneously. With a thickness of 10 inches, the outside metal is strained only to 1·05 tons, while the inside is breaking with 7 tons.

(4) The cylinders of hydraulic presses are commonly made with a thickness equal to the radius of the bore, and are supposed to be capable of working safely with 3 tons per circular inch, or $\frac{1}{\cdot7854} = 3\cdot82$ tons per square inch; but Table I. shows that with such proportions a cylinder would burst with a little less than 4 tons per square inch, and should certainly not have more than about 2 tons as a permanent load; and, indeed, in practice this is seldom exceeded. The safety valve may indicate 3 tons per circular inch, but, as usually constructed, a safety valve is a very

uncertain indicator of pressure, and the application of a correct pressure gauge generally shows that the real pressure is much less than the reputed. In the presses used for raising the Britannia Bridge, half the weight of the tube, or 700 tons, was raised by one 20-inch ram, and the pressure was therefore $\frac{700}{20^2}=1{\cdot}75$ tons per circular inch, or $\frac{700}{314}=2{\cdot}23$ tons per square inch.

(5) With comparatively thin pipes, such as are commonly used for water, and with moderate pressures, we have to consider not only the thickness necessary to bear the pressure, but also the least thickness with which it is possible to cast them. Great care is taken to keep the core central, but it is seldom perfectly so, a pipe which is intended to be $\frac{1}{2}$-inch thick being frequently $\frac{3}{8}$ths at one side and $\frac{5}{8}$ths at the other, and of course the least thickness is the measure of the strength of the pipe. In thin pipes the determination of the thickness becomes a practical question. We may give, as an empirical rule, $t=\left(\frac{\sqrt{D}}{10}+{\cdot}15\right)+\left(\frac{H\times D}{25000}\right)$ in which D = the diameter of the pipe in inches, H = the head of water in feet, and t = the thickness in inches. Table II. has been calculated by this rule. The thicknesses in the second column are suitable only for gas-pipes, &c., where the pressures are very small.

(6) The joints of water-pipes are usually made with sockets and spigots run with melted lead, and this is the best mode. Such pipes are easy to cast, and consequently cheap; the joints are more easily made than with flanges, &c.; and they admit a considerable departure from the strictly straight line, which is sometimes very convenient. The proportions of the sockets, &c., vary slightly with different makers. Table III. gives some useful particulars, average weights of stock pipes, &c.

(7) Flange pipes are not very often used for water, for the reasons given above; but they are convenient for temporary purposes, where the joints have to be frequently broken. Table IV. gives the best proportions for the flanges, bolts, &c., which will be found to differ considerably from those by many makers. The flanges of cast iron pipes are commonly made excessively large in diameter, and very light in metal.

TABLE I.—Of the Strength of 10-inch Cast Iron Pipe.

Thickness of Metal.	Strain on the Metal in Tons per Square Inch.			Bursting Pressure in Tons per Square Inch.
	Maximum.	Minimum.	Mean.	
1 inch	7·0	5·26	6·13	1·226
2	7·0	4·09	5·4025	2·161
3	7·0	3·26	4·827	2·896
4	7·0	2·65	4·359	3·485
5	7·0	2·20	3·972	3·972
6	7·0	1·85	3·6475	4·337
7	7·0	1·60	3·373	4·722
8	7·0	1·37	3·137	5·019
9	7·0	1·19	2·9306	5·275
10	7·0	1·05	2·7495	5·499

TABLE II.—Of the Thickness of Cast Iron Pipes, to bear safely different Pressures of Water.

Diameter of Pipe in Inches.	Head of Water in Feet.					
	For Gas &c.	100	250	500	750	1000
	Thickness in Inches.					
1½	·27	·28	·29	·30	·31	·33
2	·29	·3	·31	·33	·35	·37
2½	·3	·31	·33	·35	·37	·41
3	·32	·33	·35	·38	·41	·44
4	·35	·37	·39	·43	·47	·51
5	·37	·39	·42	·47	·52	·57
6	·39	·42	·45	·51	·57	·63
7	·41	·44	·48	·55	·62	·69
8	·43	·46	·51	·59	·67	·75
9	·45	·48	·53	·63	·72	·81
10	·46	·50	·56	·66	·76	·86
12	·49	·54	·61	·73	·85	·97
15	·53	·59	·68	·83	·98	1·13
18	·57	·64	·75	·93	1·11	1·29
21	·6	·69	·81	1·02	1·23	1·44
24	·64	·73	·88	1·12	1·36	1·60
30	·69	·81	1·00	1·29	1·59	1·89
36	·75	·89	1·11	1·47	1·83	2·19

TABLE III.—Of the Weights and Proportions of Cast Iron Socket Pipes for a Head of about 200 feet.

Diam. of Pipe.	Length without Socket.		Depth of Socket.	Lead Joint.	Average Weight of the Pipes.			Average Weight of Quatr. Bends.		
inch.	ft.	in.	inch.	Thickness. Depth. Weight.	cwt.	qr.	lbs.	cwt.	qr.	lbs.
1½	6	0	3	¼ × 1½ = 1·2 lbs.	0	1	14	0	1	0
2	6	0	3	¼ × 1½ = 1·4	0	2	0	0	1	2
2½	6	0	3¼	¼ × 1½ = 1·6	0	2	11	0	1	9
3	9	0	3½	¼ × 1¾ = 2·3	1	0	8	0	1	17
4	9	0	4	5/16 × 2 = 4·0	1	2	0	0	2	19
5	9	0	4	5/16 × 2 = 5·0	2	0	0	0	3	0
6	9	0	4¼	5/16 × 2¼ = 6·5	2	2	0	0	3	3
7	9	0	4¼	5/16 × 2¼ = 7·7	3	0	12	1	0	25
8	9	0	4¼	5/16 × 2¼ = 8·2	3	2	24	1	2	2
9	9	0	4½	5/16 × 2½ = 10·4	4	1	0	1	2	18
10	9	0	4½	5/16 × 2½ = 11·5	4	3	14	3	3	0
12	9	0	4½	5/16 × 2¾ = 15·0	6	2	0	3	3	21

TABLE IV.—Of the Proportions of Cast Iron Flange Pipes.

Diameter of Pipe.	Diameter of Flange.	Thickness of Flange.	No. of Bolts.	Diameter of Bolts.	Diameter of Circle of Bolts.
1½ in.	4½ in.	½ in.	3	⅜ in.	3¼ in.
2	5¼	½	3	7/16	3¾
2½	6	⅝	4	7/16	4½
3	6½	⅝	4	½	5
4	8	⅝	4	9/16	6¼
5	9¼	⅝	4	9/16	7½
6	10½	¾	6	9/16	8¾
7	12	¾	6	⅝	10
8	13¼	⅞	6	⅝	11¼
9	14½	⅞	6	⅝	12¼
10	16	1	6	¾	13½
12	18¼	1	6	¾	16

Table V.—Of Equivalent Pressures in Pounds per Square Inch, Feet of Water, and Inches of Mercury, at a Temperature of 62° Fah.

Pounds per Square Inch	Feet of Water.	Inches of Mercury.
1·	2·311	2·046
2·	4·622	4·092
3·	6·933	6·138
4·	9·244	8·184
5·	11·555	10·230
6·	13·866	12·276
7·	16·177	14·322
8·	18·488	16·368
9·	20·800	18·414
·4327	1·	·88533
·8654	2·	1·77066
1·2981	3·	2·65599
1·7308	4·	3·54132
2·1635	5·	4·42665
2·5962	6·	5·31198
3·0289	7·	6·19731
3·4616	8·	7·08264
3·8942	9·	7·96797
·48875	1·12952	1·
·97750	2·25904	2·
1·46625	3·38856	3·
1·95500	4·51808	4·
2·44375	5·64760	5·
2·93250	6·77712	6·
3·42125	7·90664	7·
3·91000	9·03616	8·
4·39875	10·16568	9·

Example.—Required the Pressure per Square Inch, and Equivalent Column of Mercury for a Head of 247 feet of Water.

Feet of Water.		lbs. per Square Inch.		Inches of Mercury.
200	=	86·54	or	177·066
40	=	17·308	,,	35·413
7	=	3·029	,,	6·197
247	=	106·877	,,	218·676

2	18	20	21	24
·204	16·56	20·45	22·53	29·45
·409	33·12	40·91	45·07	58·90
·613	49·68	61·36	67·61	88·35
·818	66·23	81·81	90·14	117·8
1·023	82·80	102·3	112·7	147·3
1·227	99·36	122·7	135·2	176·7
1·48	15·9	143·2	157·7	206·1
1·636	32·5	163·6	180·3	235·6
1·841	49·0	184·1	202·8	265·1
2·045	65·6	204·5	225·3	294·5
2·25	82·1	224·5	247·9	323·9
2·454	98·7	245·4	270·4	354·4
2·659	15·2	265·9	293·0	382·8
2·964	31·8	286·4	315·5	412·3
3·16	48·4	306·8	338·0	441·7
3·27	64·9	327·2	360·6	471·2
3·477	81·5	347·7	383·1	500·6
3·68	98·0	368·2	405·6	530·1
3·886	14·6	388·6	428·2	559·5
4·091	31·1	409·1	450·7	589·0
4·50	64·3	499·0	495·8	647·9
4·90	97·4	490·9	540·8	706·8
5·31	30·5	531·8	585·9	765·7
5·727	63·6	572·7	631·0	824·6
6·136	96·8	613·6	675·0	883·5
6·544	29·8	654·5	721·1	942·4
6·954	63·0	695·4	766·2	1001
7·36	96·1	736·3	811·3	1060
8·18	62·3	818·1	901·4	1178
8·59	95·4	859·0	946·5	1237
9·01	28·5	898·0	991·6	1296
9·42	61·6	938·9	1037	1355
9·81	94·8	981·9	1082	1414
10·23	27·9	1023	1127	1472
10·64	61·0	1064	1172	1531
11·04	94·1	1104	1217	1590
11·45	27·2	1145	1262	1649
12·26	60·3	1186	1307	1708
12·27	93·6	1227	1352	1767

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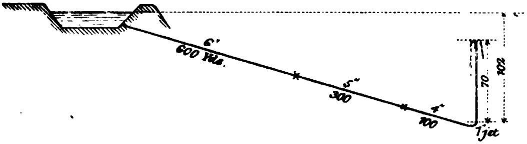
4	15	18	24	36	48	60	72	Hydraulic Radius in Feet.
0227	·1023	·1228	·1637	·2455	·3274	·4092	·4910	
14·2	95·2	104	120	148	170	190	209	·1
20·0	134	148	170	209	240	268	295	·2
24·6	165	180	209	255	295	330	360	·3
28·2	190	209	240	295	340	381	418	·4
31·6	213	233	269	330	381	426	467	·5
34·8	233	255	294	360	418	466	511	·6
37.4	252	273	317	390	449	504	546	·7
40.0	268	295	340	418	480	536	590	·8
42.6	286	313	360	443	510	571	626	·9
44·6	300	333	379	467	537	600	666	1·0
47·0	316	345	398	490	564	632	690	1·1
49·4	330	360	417	511	590	660	720	1·2
51·0	343	375	422	532	612	686	750	1·3
53·0	356	390	449	546	636	712	780	1·4
54·6	368	404	464	571	658	736	808	1·5
56·6	381	418	480	590	680	761	835	1·6
58·6	393	430	494	605	701	786	861	1·7
60·0	402	442	511	626	720	804	885	1·8
61·6	415	455	523	643	741	830	911	1·9
63·2	426	467	538	666	762	852	934	2·0
66·0	445	488	564	690	792	890	980	2·2
69·6	466	511	598	720	835	932	1021	2·4
72·4	485	528	614	750	866	970	1065	2·6
74·6	504	546	634	780	898	1008	1105	2·8
77·8	521	572	658	802	932	1042	1144	3·0
80·0	536	590	681	835	960	1072	1181	3·2
82·5	553	608	700	860	990	1107	1217	3·4
85·0	571	626	720	886	1020	1142	1254	3·6
87·3	585	646	739	910	1047	1172	1295	3·8
89·6	600	666	758	934	1074	1200	1336	4·0
94·0	632	690	797	965	1129	1264	1380	4·4
98·4	660	720	834	1021	1180	1320	1440	4·8
92	686	750	864	1063	1224	1372	1500	5·2
96	712	780	898	1092	1272	1424	1560	5·6
10	730	808	924	1142	1315	1460	1615	6·0
19	796	864	1010	1236	1424	1592	1728	7·0
27	852	934	1075	1332	1523	1704	1867	8·0
34	900	999	1138	1400	1611	1800	1998	9·0
42	952	1044	1200	1476	1702	1904	2088	10·0

Fig. 1.



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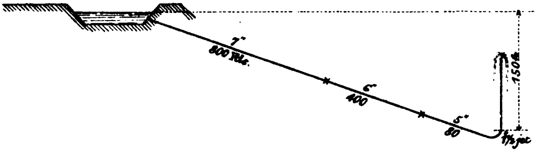

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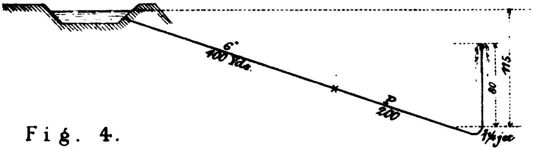

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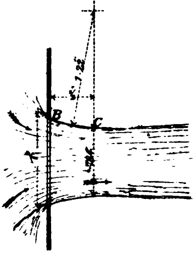

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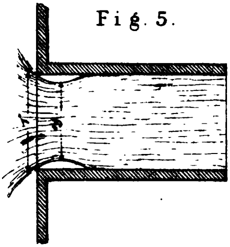

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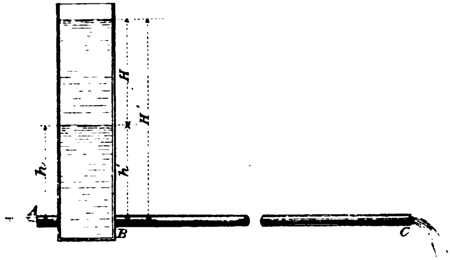
Fig. 6.



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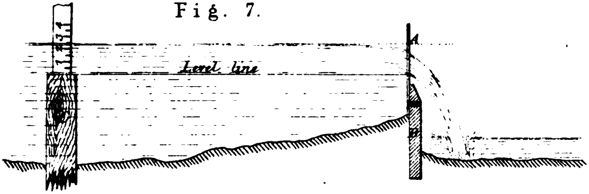
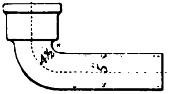
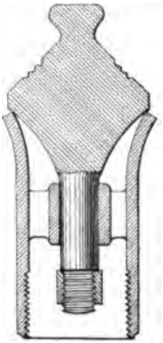


Fig. 10.

Fig. 9.





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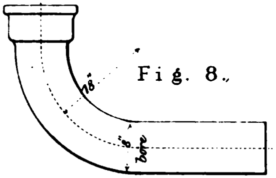

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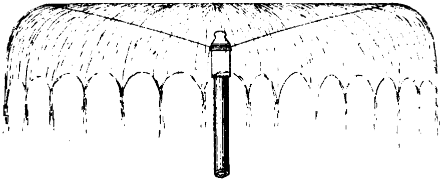
Fig. 11.



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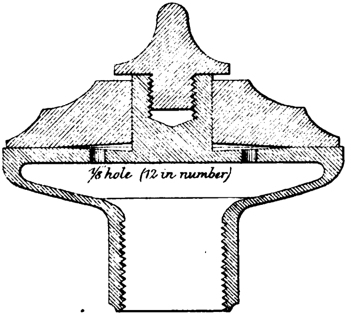

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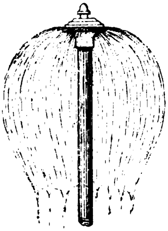

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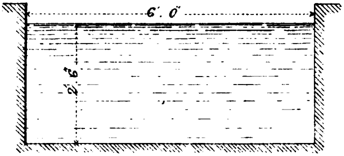

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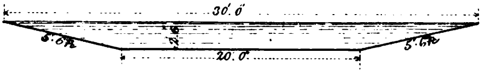

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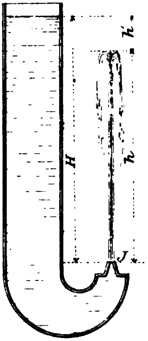
Fig. 16.



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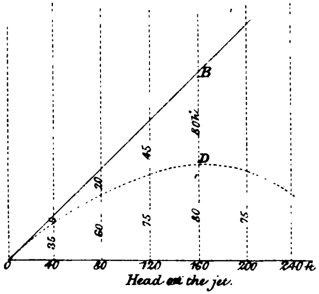

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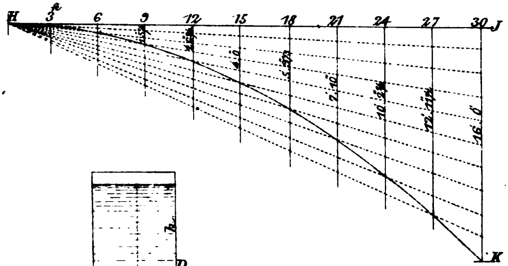

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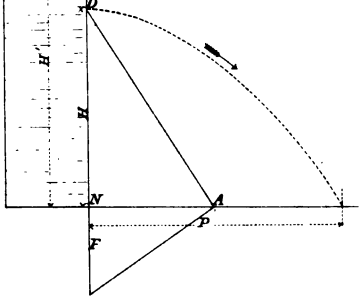

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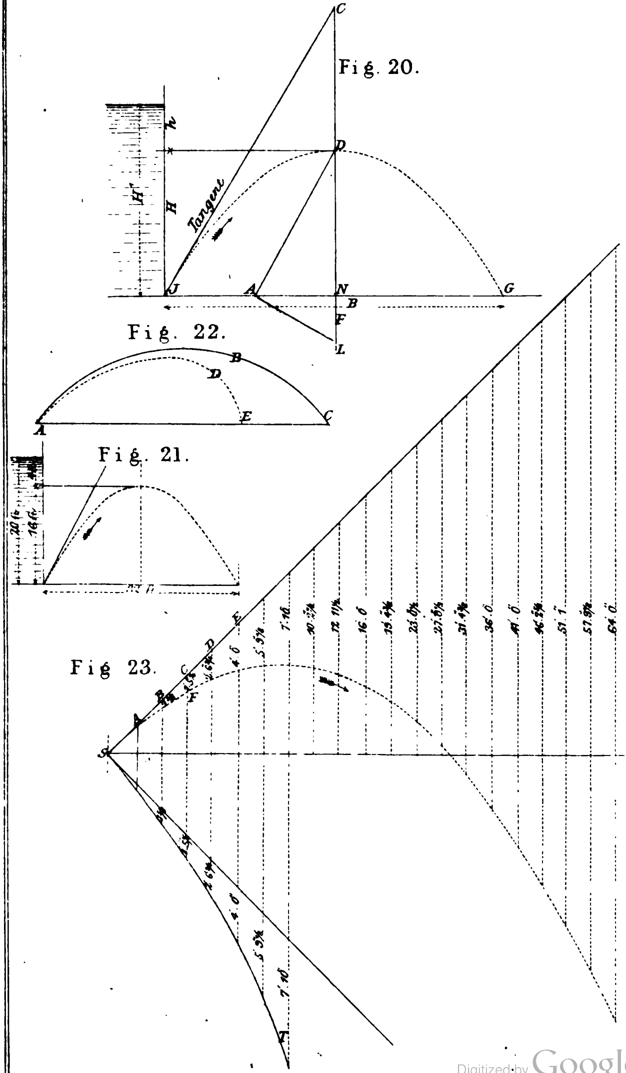

Fig. 20.

Fig. 22.

Fig. 21.

Fig 23.

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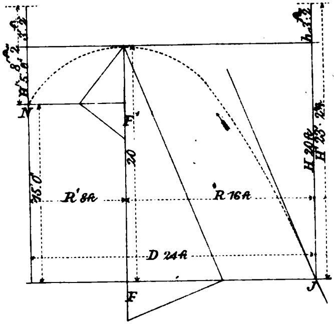
Fig. 24.



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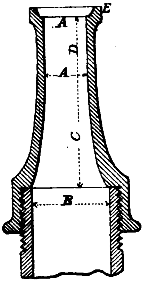

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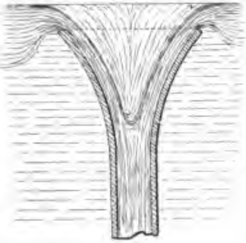

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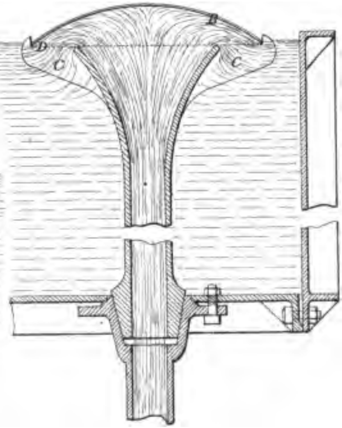

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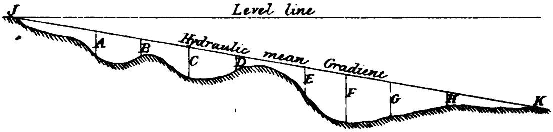
Fig. 28.



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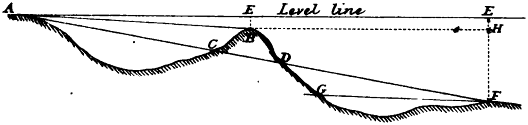

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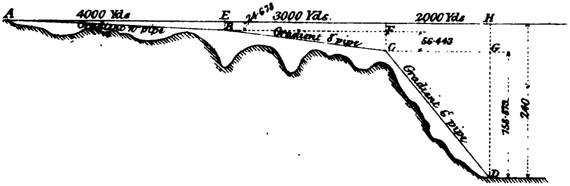

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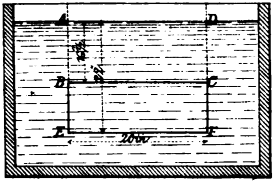
Fig. 32.



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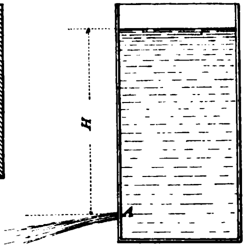

Fig. 34.

SECTION.

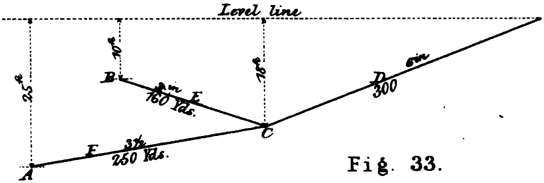

Fig. 33.

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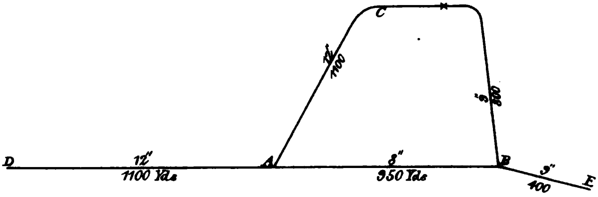

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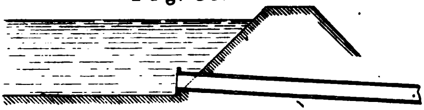

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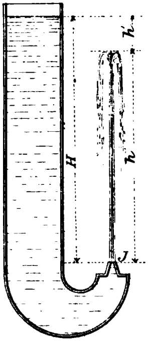

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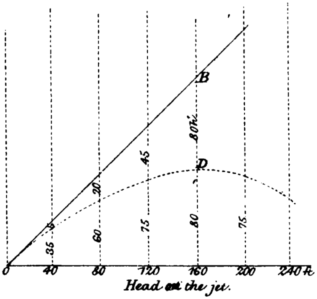

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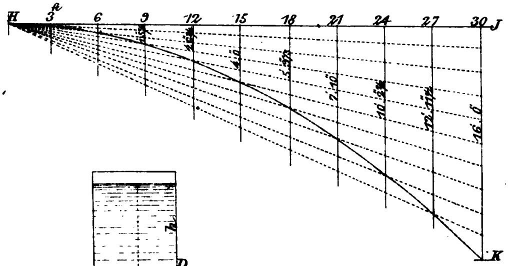

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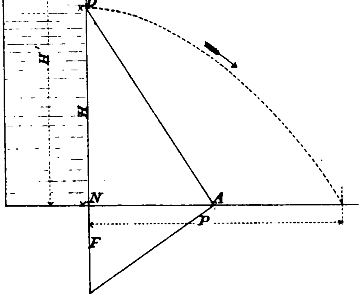

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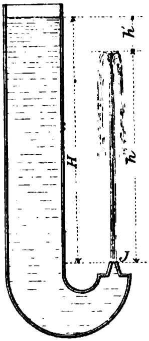

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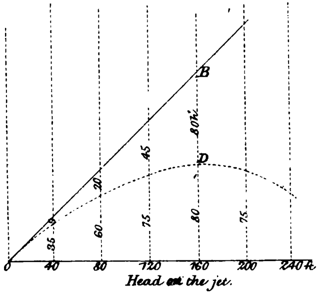

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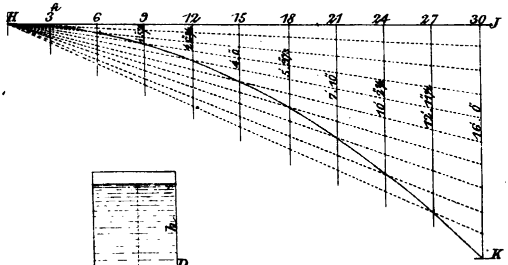

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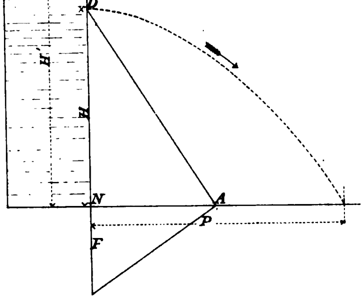

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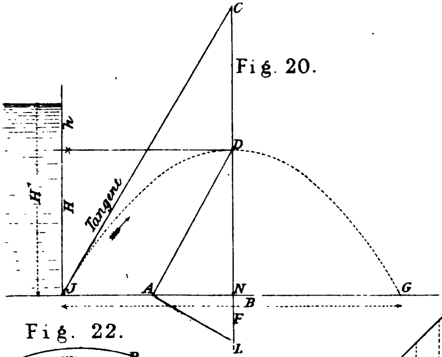

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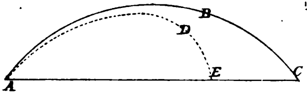

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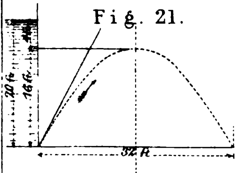

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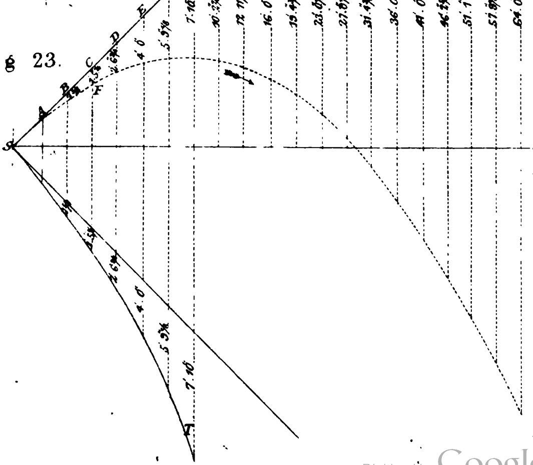

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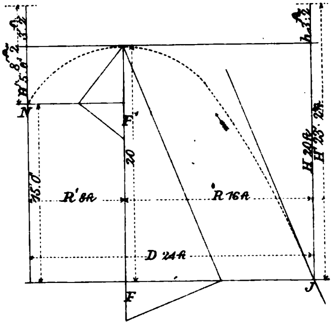

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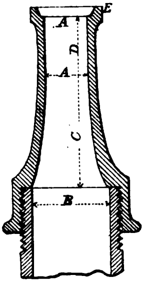

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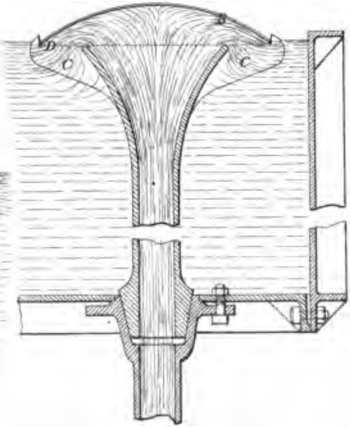

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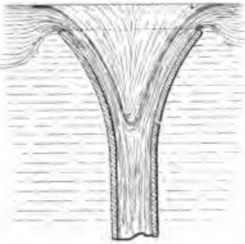

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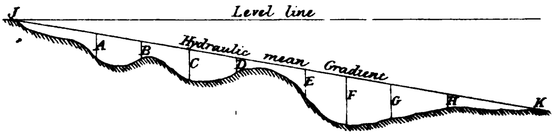

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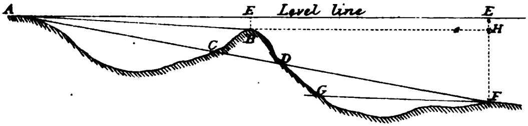

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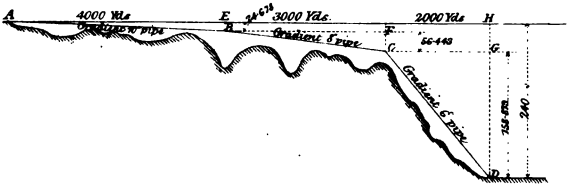

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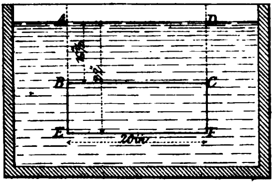

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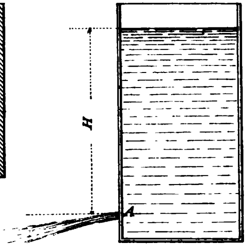

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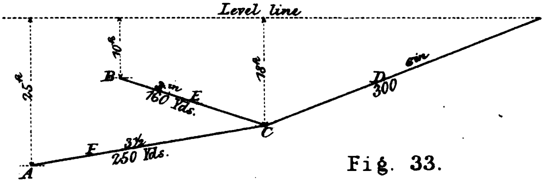

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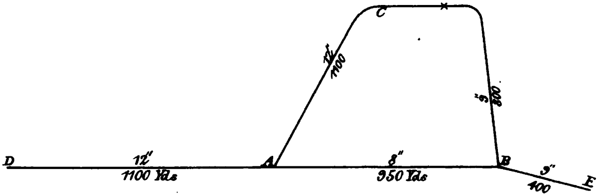

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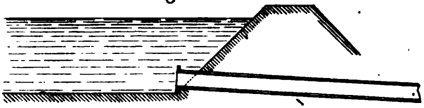

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